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ACTA RADIOLOGICA, herausgegeben von den *Gesellschaften für medizinische Radiologie* in *Dänemark, Finnland, Holland, Norwegen, Schweden* und in der *Schweiz,* enthalten Arbeiten auf den Gebieten der *Röntgenologie, Radiumtherapie, Lichttherapie* und *Elektrotherapie.* Die Beiträge werden je nach eigener Wahl des Verfassers, in deutscher, englischer oder französischer Sprache veröffentlicht. Ab 1948 erscheinen *zwei* Bände jährlich. Jeder Band enthält za 500 Seiten, in sechs Heften erscheinend. *Abonnement* bei Acta Radiologica, Stockholm 2, Schweden. **Abonnementspreis je Band:** *35 schw. Kronen, zuzügl. Postgebühren, 3 schw. Kronen für nicht-Skandinavische Länder, im voraus zu bezahlen. Einzelne Hefte 7 schw. Kronen zuzügl. Postgebühren. Die Zeitschrift wird den Beziehern bis zur Abbestellung geliefert; diese muss spätestens 10 Tage vor Beginn eines neuen Bandes bei der Redaktion eingehen.*

FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

MEDICAL RADIOPHYSICS IN SWEDEN 1920—1950[1]

by

Rolf M. Sievert

This collocation has been made for several reasons. One is that through the development of nuclear physics during the last decade, medical radiophysics has attained a more immediate interest and may be expected to become a branch of applied physics, which, within the next few years will be of very great importance. A survey of the organization of medical radiophysics in Sweden can therefore be supposed to be of some general interest, as this subject has developed along somewhat different lines in Sweden than in other countries, its various parts — research and teaching, hospital work, radiation protection and dosage control — to a large extent being combined in one and the same institute. A further reason is that a review of the development and a consideration of existing organizations may be of use in the reorganization of medical radiophysics which may be needed in other countries as well as it is in Sweden. Finally, during the most recent years, inquiries on a steadily increasing scale have come in from abroad about the supervisory activities of the Institute of Radiophysics. For this latter reason an English translation of the laws and regulations which bear upon these activities seems desirable.

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Introduction

When the first world war began in 1914, radiology was already a firmly established science in most countries. On the whole, the general physical qualities of roentgen radiation and radiation from radioactive substances were already rather well known from both the qualitative and quantitative points of view, at least in respect to absorption and distribution in irradiated bodies. The fundamental investigations of BARKLA, W. L. BRAGG, LAUE and MOSELEY had made the nature of roentgen rays clear, to a certain extent, and through the many valuable investigations by RUTHERFORD and his co-workers, a relatively thorough knowledge had been obtained of the phenomena which arise when radiation from radioactive substances penetrates different materials.

After the end of the first world war, medical radiology had reached that stage in its development where it was more generally considered from the medical view that co-operation with physicists concentrating upon medical problems was unavoidably necessary for the continued work. During the first two decades after the discovery of roentgen rays, the most important questions had concerned improvement of the technical performance of the roentgen tube and roentgen equipment. About 1918, both in roentgen diagnostics and also in roentgen therapy, the apparatuses had advanced to a rather high standard, while a large number of fundamental medico-physical questions were unanswered, inter alia, concerning measurement of radiation doses and the connection between dose and irradiation time, on one side, and the biologic effect on the other. The book by KRÖNIG and FRIEDRICH »Physikalische und biologische Grundlagen der Strahlentherapie», published in 1918, was pioneering in the new application of physics — medical radiophysics. If this monograph is read today, it is astonishing to find how the authors, with the primitive means of that time and somewhat uncertain points of departure, nevertheless, attacked, with perspicacity and success, a number of the problems which for decades thereafter were to be, and are still today in part, of primary importance to research in medical radiophysics.

In radium therapy the first two decades were characterized by the lack of access to larger quantities of radium. It first became possible

during the 1920's for a number of clinics to obtain quantities of several grams of radium.

In Sweden preparations were made for collaboration in radiology between clinicians and physicists, during the years of 1919—1920, which became of more permanent character at the end of 1920 at Radiumhemmet in Stockholm.

As is so often the case, when representatives of the so-called exact sciences turn their attention to medical or biologic questions, there was much optimism concerning the possibilities of giving substantial support to the development of medical radiology within a short time. For example, at Radiumhemmet detailed calculations and radiation measurements were started with the intention of improving results of radium application. After about two years' work, however, we found that the experienced radiotherapist, with the support of the results he saw in his daily work while using various combinations of preparations, had already arrived in a surprising number of cases at methods which gave most expedient distribution of radiation, in practice, while physical measurements and calculations had not nearly the great practical importance that had been hoped. It may be worth while to mention, therefore, that even today physicists sometimes concentrate too much on problems in which medical experience has already arrived empirically at satisfactory solutions.

The question existed in 1920 in Swedish radiology, as to whether a change-over should be made from preparations containing radium sulphate to the use of emanation preparations. Arrangements were made for such a change-over, but after studies in the U. S. A. and careful consideration, it was discovered that the radium salt preparations gave so much greater certainty and simplicity in dosage that their use should be continued. This probably has been of principal importance to radiotherapy in Sweden, as this conservative attitude was accompanied by an extraordinary advantage, namely, the same sources of irradiation and methods of treatment were used during a long period and, thereby, statistical material was obtained, based on very uniform irradiation technique. Without going into a closer discussion of the general aspects of this question here it is necessary, however, to underline the significance of the use of the same method of treatment during a sufficiently long time for statistically significant results to be obtained. Only in this manner will a comparison between earlier and later methods become possible.

During the years 1921—1922 there was not yet any proper physics laboratory at Radiumhemmet, but a small space had been arranged in the attic, in which radium measurements could be made with an instrument specially constructed for the purpose. The measurements con-

cerned the distribution of intensity with different combinations of radium preparations. Parallel to these projects, this question was also approached mathematically with the result that, with the help of different formulae, it was possible to calculate the radiation intensity around linear, ring-formed and plane preparations. Tables were collected which permitted a comparatively simple and rapid calculation of radiation distribution. It may be mentioned that by this method it was shown that the isodose curves with a ring-formed applicator were Cassinic curves, and that such an applicator could be used advantageously for treatment in special cases. However, the method never attained any great use in Sweden, but was later taken up in England on the suggestion of SOUTTAR 1931.[1]

1. The Physics Laboratory of the Radiumhemmet 1924—1937

When Radiumhemmet was enlarged in 1923—24 by a small addition adjacent to its existing building at Fjällgatan 23, two small rooms and a dark-room were arranged on the ground floor as a physics laboratory. In the larger room a section was partitioned off with lead protection, so that a roentgen tube could be connected to one of the high voltage plants in the therapy department. A physicist and a young assistant were employed. The principal duty of the physics laboratory then was to exercise technical and physical control of roentgen equipment and roentgen and radium dosages at Radiumhemmet, and to conduct research in connection therewith. Also included was a relatively comprehensive work with control measuring of the radium preparations of Radiumhemmet and radium quantities which were purchased and mounted under the supervision of the laboratory during the immediately succeeding years. Radioactivity determinations were also made for other hospitals in the country. For these different purposes new measurement devices were constructed at the laboratory, as well as a number of instruments for research which was being done by the doctors at Radiumhemmet. From the very first the laboratory became a generally consulted control institution for radium determinations and issued certificates for radioactive preparations. (Fig. 1.)

In the autumn of 1925 an investigation of dosages was made in all of the hospitals in the country where roentgen therapy was conducted under expert direction, and information was correlated concerning doses which were considered at the various hospitals to produce a skin erythema dose. It then became apparent that these doses varied so widely that the dosage level in certain roentgen departments was twice as high as

[1] SOUTTAR, H. S.: Brit. Journ. Rad. 4, p. 681, 1931.

RADIUMHEMMETS
FYSISKA LABORATORIUM
STOCKHOLM

Stockholm the ..... of ..... 19 ....

CERTIFICATE No. .....

THE PREPARATION.

Shape: .....
Dimensions: .....
Weight: .....
Identification marks: .....
Filter (according to statement): .....
Contents (according to statement): .....
Handed in for examination on the ..... of ..... 19 .... by .....
.....
Returned on the ..... of ..... 19 .... to .....
.....

METHOD OF MEASURING.

The γ-activity of the preparation has been compared with that of .....
by the aid of .....
.....
.....
.....
.....

QUANTITY OF RADIUM IN THE PREPARATION.

Provided that the preparation contains no other active substance than radium and its disintegration products, and provided also that the statement recorded above regarding the filter is correct, this preparation contains .....
milligrammes of radium element.

This result is correct within .....

Chief of
the Radiumhemmet Physical Laboratory.

Fig. 1.

the average while in others the dosage was less than half average. For this reason the physics laboratory at Radiumhemmet suggested in 1925 that a mobile department should be established, under the direction of the laboratory, for the purpose of periodically visiting the hospitals in Sweden which carried out roentgen therapy under expert management, and there carefully check the roentgen equipment and standardize dosages and important factors for them. For this purpose a portable dosimeter and a stationary intensimeter were built, the latter designed to be installed in the treatment departments for daily control of the constancy of the roentgen radiation. During a visit to Physikalisch-

Technische Reichsanstalt, Charlottenburg, in 1925 the former instrument was calibrated using the then new R-unit.

The mobile measuring department, which was financed through fees according to an established scale of charges, was consulted from the very beginning by nearly all of the roentgen therapy departments in the country, which is still the case. An assistant physicist was employed by the mobile department who was able to take over complete charge of its operations within a short time. He also participated in the research work and in the beginning concentrated especially on problems concerning the technical qualities of roentgen apparatus.

From that time the first Swedish investigations are found which deal with radiation protection in diagnostics and therapy work. Systematic investigations of the efficacy of various building materials as protection against radiation were carried out. The distribution of intensity in teleradium treatment with the radium bomb built by LYSHOLM was investigated. In 1926 the condenser dosimeter was reported, which constituted a predecessor to the condenser chamber. The question of filters in roentgen therapy came up for discussion and, in 1928, led to the construction of a combined tin filter (0.44 Sn + 0.25 Cu + 1.00 Al) which since that time has been used extensively for deep therapy in Sweden and also in some places abroad.

That the laboratory did not have a roentgen apparatus at its own disposal during these first years, and therefore must postpone the work until those times of day or night when roentgen treatment was not taking place, was a considerable difficulty. The laboratory space proved to be altogether too small also, especially considering that the various radiation investigations disturbed each other.

The second International Congress of Radiology in Stockholm in 1928 was of great importance to the development of medical radiophysics. The resolution of the Congress concerning an international unit for roentgen radiation, the r-unit, and its recommendations concerning radiation protection in radiologic work constituted a valuable basis for the physicists' continued work in radiology. On the committees which worked out proposals on these matters, physicists from the Physics laboratory of Radiumhemmet took an active part.

When Radiumhemmet was enlarged in 1929 with an annex in a neighbouring property, the physics laboratory received considerably larger new quarters. In the cellar of Fjällgatan 20 A, a roentgen ray standardizing laboratory was established and, through the addition of a new storey the laboratory was enlarged to include four laboratory rooms as well as a writing room, a roentgen ray machine room with control room, a small workshop and a dark-room. The personnel was also increased and the possibilities for research work became substantially improved.

During 1929 a specialist in biochemics and biology was attached to the laboratory, which proved to be of great importance to future development. In 1930 an extra physicist was appointed.

Among the problems which were taken under consideration may be mentioned: the importance of the time factor to biologic radiation-effect, intensity of γ-radiation at the surface and vicinity of radium needles, the secondary β-radiation from the surface of radium preparations, and investigations concerning the diffuse gamma radiation in work rooms. In addition, a number of measuring instruments were constructed at the laboratory for the measurement of radioactive substances, among others a device for the determination of the ratio between mesothorium, radiothorium and radium in radioactive preparations according to BOTHE. Certain technical roentgen work, such as the design of a shock proof and ray proof roentgen tube housing, was also published.

During 1931—1932 the research activities appreciably increased. The condenser chamber method, which was later developed into a method of essential importance to the institution, was worked out during these years and subjected to thorough testing. A standard chamber for the measurement of roentgen radiation in international r-units was also constructed and was accorded a permanent installation. In collaboration between physicists and biologists, the investigations concerning the time factor were continued. In 1932 two doctors' theses were published from the institution. During 1933—1934 foreign medical radiophysicists also visited the institution for shorter or longer periods and participated in the work there.

Of the articles which were published during these years might be mentioned: continued investigations of the time factor, especially with very short times; measurements concerning radiation distribution with teleradium apparatuses; descriptions of a new teleradium apparatus and improvements of the same, as well as construction of new types of condenser chambers. In a number of articles some radiation protection questions and dosage problems and the filtering in roentgen therapy were also discussed. By invitation, at the International Congress of Radiology in Zurich in 1934, a representative of the laboratory read a paper on the subject, »Erd-Gamma-Strahlung und Ultrastrahlung». The condenser chamber method had now been further developed and was used for investigation of the natural γ-radiation in buildings.

Investigations were also performed regarding ionization at high gas pressures and the quality of certain tubes for roentgen diagnostics. Units for roentgen and radium radiation were discussed in some articles. Especially the question as to whether it was advisable or not to use the r-unit for γ-radiation also was the subject of repeated contributions. With regard to the great difference in secondary radiation conditions,

especially in reference to the β-radiation, it was considered at the physics laboratory at Radiumhemmet that the r-unit in the form in which it had been defined at the International Congress of Radiology in Stockholm 1928, was not appropriate as a unit for γ-radiation.

For the 70th birthday of H. M. King Gustaf V in 1928, a National Jubilee Fund was collected and, according to the King's wish, used for the purpose of investigating and fighting cancer diseases. Thus the King Gustaf V's Jubilee Fund came into being which made a considerable contribution toward the erection of a new building for Radiumhemmet and also permitted the construction of two new buildings for research institutions, one for radiopathology and one for radiophysics. Radiumhemmet and both of the research departments formed the Jubilee Clinic of King Gustaf V, which was to constitute the radiotherapeutic clinic of a new state hospital then under construction, the Karolinska sjukhuset. During 1934—1936 plans were made for the Jubilee Clinic which was built in 1936—1937. The research workers of the physics laboratory participated in these preparations, and this took up a considerable part of their time. These circumstances and the equipping of the new institution caused a sharp decline in research activities during the period 1935—1939. It was necessary to interrupt a number of projects for a time which later, because of the war, were to be further postponed or completely abandoned. A number of results had to be published in preliminary or incomplete form. From this period we might mention papers on dosage conditions in the prevailing roentgen therapy technique in Sweden, radiation measurements on personnel in radiologic work, the therapeutic significance of secondary β-radiation, continued investigations of the time factor, and a further number of biologic and physical-technical papers. An investigation of the development of Drosophila Melanogaster, with screening off of the natural surrounding radiation, was also carried out in 1935. It was found that the period of development became longer with a lower ionization level. This peculiar result was reached under careful control of other physical conditions, especially the temperature. The result could not be explained on the basis of any other factor than radiation conditions. Work with roentgen microphotographic methods was also taken up during this time, but had to be interrupted for the aforementioned reasons.

Two new types of teleradium apparatuses were constructed during 1935—1937 with which the radiation protection, especially with regard to the personnel, was materially improved. In one of these devices a pneumatic arrangement and in the other a mechanical one was used to transport the radium to a protective lead container before the treatment room was entered. The question of protective walls in the teleradium department was also the subject of an investigation and an iron ore

concrete, which has about twice as much protective power against radiation as ordinary concrete, was developed. The walls and ceiling in the present teleradium department at Radiumhemmet are made of this material. A protective mantle and a cooling pump for roentgen therapy tubes were constructed which, especially the former, have come into extensive use in Sweden.

The fact that Radiumhemmet was a relatively small hospital operated by a private foundation (The Cancer Society of Stockholm) had a strong influence on the work of the physics laboratory there. Co-operation between physicists and doctors was extraordinarily good, decisions about extra personnel or the obtaining of instruments could be made without delay and a general enthusiasm for the work existed. The founder of Radiumhemmet, GÖSTA FORSSELL, gave his personal support to every idea that he considered advantageous and overcame any difficulties concerning the procurement of necessary resources for its realization. To gain practical experience the physicists often participated in the treatment of patients and the daily ward-rounds. Through this intimate contact with the doctors they received a good insight into the existing need for improved treatment, radiation measurement and dosage techniques. Thus, the comprehensive testing of the condenser chamber method was carried out in close collaboration with the clinicians.

During the last years of activity of the old physics laboratory of Radiumhemmet, more or less regular lectures and demonstrations for the doctors of Radiumhemmet also took place at the laboratory, especially concerning projects in which co-operation was necessary.

2. The Institute of Radiophysics 1938—1950

In the spring of 1938 the physics laboratory at Radiumhemmet was moved over to the Karolinska sjukhuset and was renamed The Institute of Radiophysics. 1938 and the beginning of 1939 were mainly used for the equipping of the premises and for installation and testing of standard apparatuses intended for measurement of roentgen radiation and radioactive preparations. During the time when the work in the laboratories had not yet started, a comprehensive statistical investigation was begun of the distribution of cancer in Stockholm, especially with respect to the location of the residence of the patient during and before the illness and to social factors. The principal result of the investigation, which could not be completed because of the outbreak of the world war and therefore was not published, was that the cancer diseases in Stockholm generally seemed to be distributed at random, with the exception that certain localization of cancer occurred especially where the sanitary conditions were poor. An apparent increase in the incidence of lung

cancer could also be demonstrated during the 10 year period which was subject to investigation.

After the move over to the Karolinska sjukhuset the government had completely taken over the operation of Radiumhemmet. Such was not the case with the Institutes of Radiophysics and Radiopathology, however, where only the personnel responsible for the routine work for Radiumhemmet were governmentally employed. The directors and the greater part of the rest of the personnel were in the service of the Jubilee Fund. For co-operation between the three departments of the Jubilee Clinic, Radiumhemmet, the Institute of Radiopathology and the Institute of Radiophysics, there was a research council consisting of Professors G. FORSSELL and F. HENSCHEN and the directors for the General and Gynaecological Departments of Radiumhemmet, and the directors of the Institutes of Radiopathology and Radiophysics. Certain administrative difficulties were unavoidable, however. For this reason, the council asked the directors of the two research institutes to make detailed reports with the help of which the research council presented a proposal to the Jubilee Fund which affected the Institute of Radiophysics in the following manner:

The director of the Institute was also to be professor of radiophysics at the Karolinska institutet but with limited teaching duties. Practically all employees at the Institute of Radiophysics were transferred to permanent state appointment. The Jubilee Fund, however, was also to continue to contribute to the research activities of the Institute and provisionally to pay the salary of a medical expert.

An Act about supervision of radiologic work, etc. was to be promulgated, according to which the Institute of Radiophysics, under the direction of the Royal Medical Board, was to supervise the observance of the Act and, in return for fees from owners of establishments for work with roentgen rays and radioactive substances and also storage of such substances, was to make periodic inspections of such establishments. In this inspection activity, the previously mentioned mobile measuring department for control of dosage in the roentgen therapy departments of the country was to be included. Mounting of radioactive preparations, radioactivity measurements, investigations of radiation protection material, etc., in addition, were to be carried out by the Institute according to a proposed tariff. The personnel to be employed for supervisory activities were intended to have opportunity to participate also, to a certain extent, in the research work and in the current radiophysical work for Radiumhemmet. The Institute, as previously, was to be at the disposal of the Jubilee Fund for the performance of the work which fell within the programme of the Fund, and at the disposal of the Karolinska sjukhuset for work in radiation physics in connection with treatment and for instruction and research.

There was to be a council for collaboration between the three departments of the Jubilee Clinic, consisting of a chairman selected by the Jubilee Fund, the heads of the departments of Radiumhemmet and the directors for the Institutes of Radiopathology and Radiophysics.

The fees for the supervisory activites, which were to be paid into the State Treasury, were so calculated as to cover the direct costs of the operations and leave a surplus of approximately 20 percent, which was considered reasonable taking into account that the research activities and work with treatment at the Karolinska sjukhuset were necessary to maintain the competence of the supervisory personnel within the field of medical radiophysics.

The Jubilee Fund was to pay an initial sum to the State, from which the annual returns were calculated to compensate the obligations taken over by the State according to the proposal, insofar as these concerned research and instruction activities. Also included in the proposal was a small enlargement of the premises of the Institute of Radiophysics for a library and a radium mounting and radium measurement laboratory for which a special building was to be constructed.

The proposal which was presented to His Royal Majesty in November, 1939, occasioned a Government Bill to Parliament in 1941, which approved it with minor alterations.

Some days after the second world war broke out in 1939, the director of the Institute of Radiophysics had taken the initiative in an organization of Swedish physicists for the performance of physical-technical research activities in the interest of defence. Thus the Institute was occupied to a very great extent up to the end of the war with military research problems. Only the routine work for Radiumhemmet and the dosage and radiation protection control prescribed by law, as well as certain biochemical, biological and haematologic research work continued relatively unaffected during that time. The laboratory space and workshop of the Institute were used mainly for work in what was called military physics. The military physics activities were conducted by the Swedish National Committee of Physics with the director of the Institute of Radiophysics as leader and with the Institute of Radiophysics as centre point. At the end of the war in 1945 the military work was taken over by a government organization called The Research Institute of National Defence, and the Institute of Radiophysics was able to return to its original activities. Valuable time had been lost, however, and many years passed, before research activities and collaboration with Radiumhemmet could be taken up again to their full extent. A contributing cause for this was the supervisory activity which demanded steadily increasing personnel. Even though the Institute receives interesting and important material for investigation through supervisory activities, which include research pro-

blems, nevertheless, the routine work constitutes a serious hindrance to research, as the legally prescribed inspections must naturally take precedence over research work which, as a rule, can be deferred to a later date.

During the period 1939—1945, some investigations carried out before the war were published. Among them must be mentioned papers concerning ionization in biologic objects, biologic effect of radiation in magnetic fields, effect of radiation on certain enzymes, distribution of radiation with a new method of intra-uterine radium application, and the dependence of radiation upon the thickness of the walls of the roentgen tube. In addition, a doctor's thesis on the effect of radiation on the fungus Phycomyces Blakesleeanus had also been published in 1943.

During the reorganization of research the following points were considered:

Atomic energy research had made the problems of radiation protection urgent. The use of neutrons and roentgen rays generated with extremely high energy was of current interest but required very great resources. Furthermore, the previously available apparatuses in this field were not yet adapted for practical therapeutic use. At great cost experiments within these new branches were already under way in other countries. Radioactive isotopes had a steadily increasing significance for practical purposes and would soon play an important rôle also in supervisory activities.

With these points of departure, after its renewed start in 1945, the Institute of Radiophysics, beside general biological radiation research was especially interested in the following problems:

The production of extremely intense roentgen radiation with flashes of very short duration and investigation of its biologic effects.

Investigation of the biologic effects of small doses and of changes in the natural radiation (γ-radiation, cosmic radiation).

Determinations of the γ-radiation from the human body, both in normal cases and also when, through carelessness or otherwise, γ-radiating substances have been stored in it, and, in conjunction with this, measurements of radioactivity of expired air, body fluids, and tissues.

Investigations of the mechanism of biologic radiation effects, especially concerning the possibility of increasing or decreasing the radiosensibility through various measures.

Statistical investigations of the correlation between changes in blood picture or other physiologic radiation effects, and irradiation in radiologic work.

The development of new methods especially for the measurement of radiation doses in treatment with isotopes, and in irradiation with neutrons.

The reason for giving the above information is that the research work now taking place is, to a certain degree, illustrative of those principles which, in the author's opinion, should be the basis for the activity of an institution which is responsible for development within the sphere of radiation dosage and radiation protection.

This research programme has hitherto occasioned only a few publications from the Institute of Radiophysics. Among them we might mention investigations on radiation effects on catalase and on the distribution of radioactive isotopes in tumour and normal tissues, papers on the blood picture in personnel in radiological work and a description of a standard measuring device for determining in roentgen equivalent units the tissue dose from radioactive isotopes. The present issue contains further contributions.

It should also be mentioned that there are physical laboratories at the Jubilee Clinics of Lund and Gothenburg. These clinics were like the Jubilee Clinic in Stockholm built on the initiative of King Gustaf V's Jubilee Fund. In Lund, where the laboratory came into being in 1941, a physicist was appointed who has occupied the position of assistant professor since 1949.

On Page 245 is given a list of references to the papers published from the radiophysical laboratories of Sweden from 1921 to 1949.

3. The Present Organization of the Institute of Radiophysics

The Institute of Radiophysics is part of the King Gustaf V's Jubilee Clinic and also the Department of Radiophysics of the medical school in Stockholm, the Karolinska Institutet. The present organization of the Institute is shown in the following:

The chief of the Institute is Professor of Radiophysics at the Karolinska institutet. His educational duties are limited and can be taken over in part by assistant professors.

The Institute consists of:

Department A for control of roentgen establishments for diagnostics and for technical, scientific and instructional purposes. The chief of this department is Dr. M. HELDE.

Department B for the control of roentgen treatment establishments. The chief of this department, Dr. R. THORÆUS, is also responsible for calibration of dosimeters in r-units and testing of radiation protection material.

Department C for the control of protective devices for radioactive preparations and for testing and mounting of such preparations. The

chief of this department is Dr. S. BENNER. He is also in charge of the radon laboratory and the measuring laboratory for radioactive substances.

A *biological and biochemical laboratory* for radiation research work. The chief for this laboratory, which has no routine work, is Dr. A. FORSSBERG.

The chiefs of the above four departments are Assistant Professors.

A special *laboratory for blood investigations* exists under the leadership of a medical expert (B. SWEDIN) who has to examine the medical certificates regarding those who work with roentgen rays and radioactive substances and are subject to supervision. The medical expert only spends a few hours every week at the Institute and works mainly in an advisory capacity. The work of the laboratory is carried out in close collaboration with the department chiefs, especially the chief of Department A who is responsible for most of the supervisory activity.

A man with technical training is in charge of the *drawing office* and the *instrument workshop*. A physicist who is a qualified engineer is responsible for the work carried out in the *high voltage laboratory*.

Research activities

Although the chief of the Institute largely conducts these activities, the assistant professors have, nevertheless, a comparatively free status and are able to take up, to the extent that time permits, whatever research problems they wish, within the sphere of activity of the institution, for which the technical requirements with regard to laboratories, apparatus and assistance are available. The kinds of research problems which have been or are subject to investigations appear in the first part of this paper. Some of the most important problems concern development work in irradiation methods and radiation measurement methods, designed mainly to improve the physical-technical possibilities of the radiation treatment at Radiumhemmet. The physicists at the Institute collaborate with the doctors at Radiumhemmet in research work of different kinds especially when dosage measurements and calculations are required. Important research problems also exist in connection with the supervisory activities. One of the physicists, together with the medical expert, also conducts the research, which concerns the correlation between observed radiation effects and the irradiation doses received in radiologic work, especially the statistical parts of this work.

The biologic and biochemical laboratory is especially occupied with investigations concerning the mechanism of biologic radiation effect. Thus, at present, experiments with enzyme systems and with a number of simple organisms are going on. The physicists also make use of

biological objects as test objects for investigations where the physical factors are of primary importance. Investigations of cancer reactions and the distribution of radioactive isotopes in organisms are also studied by the radiation biologist in collaboration with the doctors of Radiumhemmet. Irradiation of biologic objects is also done for outside researchers, especially during recent years for genetic investigations.

The drawing office and workshop of the Institute are practically entirely engaged in the production of instruments and experimental devices for research.

In order to promote good co-operation between the various departments of the Institute, a staff meeting to which all workers with university degrees have admission, is held once a month. The meetings take up an entire day, as a rule. The agenda includes short statements about the current research work preferably concerning results and difficulties encountered in experiments, of technical or fundamental nature, reports on literature, announcement of recent books, journals and catalogues, as well as proposals on the procurement of instruments and other equipment, books and periodicals.

Hospital physics and instruction at Radiumhemmet

One of the physicists is always available for the daily needs of radiation measurements and consultations on the treatment techniques for the patients at Radiumhemmet. He has to control the routine radiation measurements which are carried out in the roentgen and radium departments of Radiumhemmet, take part at least once a week in the daily rounds of the general department of Radiumhemmet, and inspect the roentgen and teleradium departments at least twice a week. The physicist in charge for the day also has to perform the special dosage measurements, or radiation protection measurements, that the hospital doctors wish to have performed or which he himself finds desirable.

The roentgen tubes and the technical devices of the roentgen apparatuses as well as the radium supply are controlled at regular intervals.

The daily radiation measurements, which are performed according to the condenser chamber method, are mainly for control of the radiation dose on the irradiated field. Also, a number of dose measurements are carried out with condenser chambers in body cavities or during operations. Figure 2 shows a typical report concerning a radiation measurement at roentgen treatment of an oesophagus tumour.

The instruction at Radiumhemmet is intended for the doctors who work there after having completed their medical examinations. It includes 20 lectures and demonstrations annually, as well as 20 hours of practical exercises, which take place either in the roentgen depart-

RADIOFYSISKA INSTITUTIONEN

PROTOKOLL Nr 2083 a

Pat. namn: Elsa Lovisa Karlsson Datum: 9.12.49

Journ. nr 16231/49

Diagnos: Ca oesophagi

Rörspänning: 170 kV

Rörström: 20 mA

Fältstorlek: 75 cm²

Beströlningstid: 27,1 min.

Avstånd: 60 cm.

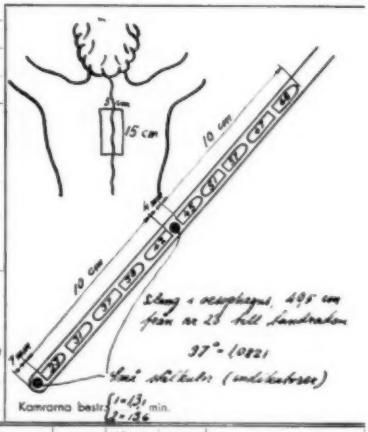
Filtrum: Sn

Dos: 600 r

Apparat: S4

Tillägg: 5 % för bländare avlångt fält

Båga vården runt underlag



	Kammare nr	Spänningsförlust skaldelar	Spänningsförlust volt (d)	d—r	d_m	Dos r	Medelvärde r	Differens %	Anm.
1.	9	42,0	193,9		206,4	[618]			
	201	37,8	143,6		162,9	304	304		
									32°
2.	61	37,2	143,6		162,9	317			
	202	34,0	150,4		160,1	312	315		
							619	+3	
									Dipplos %
	29	19,7	74,4		80,5	147	147		24
	37	23,0	87,0		94,1	174			
	31	23,0	87,0		94,1	167	171		28
	42	20,9	79,0		85,6	174			
	38	21,8	82,4		89,2	187	181		29
	61	24,0	90,8		98,3	199			
	45	23,6	89,3		96,6	185	192		31
	57	40,9	79,0		85,5	174			
	47	21,6	81,7		88,4	159	166		27
	68	2,0	16,4		17,7	33	33		5

x) Tillägg Sign. ob

Fig. 2.

ments of Radiumhemmet or in the laboratories of the Institute of Radiophysics. As the instruction is not yet obligatory, it has not been possible to give it the permanent form which, especially lately, has proved desirable.

Supervisory activities

As has already been mentioned, since the first of July, 1941, there has been an Act in Sweden concerning supervision of radiologic work.

The Act, which was drawn up by the Institute of Radiophysics in collaboration with legal experts, after a minor change in 1945, has the following wording:

Act Concerning Supervision of Radiologic Work etc.

(SFS No. 334/1941 and 267/1945)

1 §.

In this Act radiologic work means work which includes use of roentgen rays, generated with a voltage of more than 5,000 volts, or radioactive substance exceeding a certain quantity which the Royal Medical Board is authorised to determine.

Radiologic work may be conducted only with permission from the Royal Medical Board.

Permission from the Royal Medical Board for the possession, without connection with radiologic work, of radioactive substance, exceeding the quantity determined by the Royal Medical Board, is also necessary.

2 §.

An application for permission to conduct radiologic work shall contain the following information:

type of radiologic work to be conducted;

location of work;

type of roentgen apparatus and highest voltage and milliamperage of the roentgen tube or, concerning work with radioactive substance, its quantity and nature;

the additional aids which are intended for use in the work, to the extent to which knowledge thereof may be assumed to be of significance in the consideration of the application;

the person who shall direct the work and his qualifications for it; and

the number of persons that it is estimated shall be engaged in the work.

In application for permission to possess radioactive substance, information shall be given about:

quantity and nature of the substance and

the location and the detailed arrangements for storage of the substance.

Application shall be drawn up according to the forms prescribed by the Royal Medical Board.

3 §.

The Royal Medical Board has the right to prescribe the obligation to observe special regulations issued by the Board as a condition to the holding of a license.

If the permission applies to conduct of radiologic work, these regulations shall be designed to gain the greatest possible security against causing injury, through the effect of roentgen rays or radiation from radioactive substance, to anyone who is engaged in the work, or any person or animal that is the subject of radiologic examination or treatment, or anyone who is casually present where such work is being carried out.

If it is a matter of possession of radioactive substance, the intention of the regulations shall be, that the substance be so stored that no injury be caused to anyone through the radiations emanating therefrom.

4 §.

The person who has been granted a license according to this Act shall notify the Royal Medical Board without delay:

a) if radiologic work, which according to the provisions of the license shall be conducted at a certain place, is moved to other premises other than incidentally, or if the premises at which the work is conducted, are appreciably reconstructed;

b) if roentgen apparatus is exchanged or such apparatus or appurtenant devices undergo appreciable change;

c) if the person who is in charge of radiologic work according to application or notification made previously, is succeeded by another person;

d) if the quantity of radioactive substance, which is used in radiologic work or is otherwise possessed, is appreciably increased or if important change has taken place in the manner of storage of such substance; and

e) if the person, who conducted radiologic work, has ceased the work or if the quantity of radioactive substance, which is possessed without connection with radiologic work, has decreased to or below the quantity determined by the Royal Medical Board.

The Royal Medical Board has the right, when the notification received so occasions, to recall the license issued.

5 §.

Concerning application for license and notification according to the first part under 4 § a)—d), the Royal Medical Board shall ask for the recommendation of the Institute of Radiophysics. Provided the Royal Medical Board so decrees or the Institute otherwise finds it necessary, before such a recommendation is given, inspection of the place of work or storage shall be made through the Institute.

6 §.

Supervision of the observance of this Act and of instructions issued on the basis of the same shall be exercised by the Institute of Radiophysics and officers employed at the Institute (supervisors) under the supervision and guidance of the Royal Medical Board.

7 §.

Supervisors shall inspect places where radiologic work is conducted or radioactive substance is stored. Inspection shall take place at regular intervals when not otherwise called for by special cause.

At inspections the supervisor has the right to make tests and investigations to control that protection instructions issued are properly observed.

If the supervisor finds that protective instructions beyond those issued by the Royal Medical Board are needed, or that instructions issued have not been observed, the supervisor shall report the circumstances to the Medical Board. If it is a question of issuance of further protection instructions the supervisor has the right, however, where the observance of the instructions is not accompanied by large expense or inconvenience, to give them himself.

More detailed instructions for the exercise of supervision will be decreed by the King.

8 §.

Where special conditions demand it the Royal Medical Board has the right to decree that an establishment for radiologic work shall discontinue operations until those measures prescribed in consequence of inspection, or otherwise, have been effected.

If the person who was granted the license to conduct radiologic work or possess

radioactive substance has not observed the protection instructions issued by the Medical Board or the supervisor, the Medical Board has the right to rescind the license issued.

9 §.

The person who conducts radiologic work or possesses radioactive substance, immediately after cognizance of occurrence of injury which may be assumed to have connection with the work or the possession of such substance and to be of the nature that is described in 3 §, shall report the same to the Institute of Radiophysics.

10 §.

The general instructions, over and above what this Act contains, which may be required to forestall injury through the effects of roentgen rays or radioactive substance, are to be issued by the Royal Medical Board after consultation with the National Insurance Board.

11 §.

When a matter covered by this Act is also dependent upon application of instructions which are issued concerning installation and care of power current installations, the National Board of Commerce shall be consulted.

12 §.

In radiologic work no other persons must be employed than those who, on medical examination, are found not to show sickness or weakness which may be considered to make them especially subject to the health risks connected with the work.

Persons employed in radiologic work shall periodically undergo investigations concerning their condition of health.

More detailed instructions concerning examination and investigation that are referred to in this paragraph, will be decreed by the King.

13 §.

A person who has been granted license according to this Act shall pay a fee annually to the National Treasury, in the amount and manner decided by the King, as contribution toward defrayment of expenses for supervision according to the Act. If the fee is not paid at the time that is thus directed, the Royal Medical Board has the right to rescind the license.

Instruction and research activities which are not conducted for profit are not liable to charge.

It devolves upon the King to determine the scale of charges for payment in both inspections according to 5 § as result of application for license, and also examination and inspection as referred to in 12 §. Expenses for abovementioned inspection according to 5 § as well as for investigation according to the 2nd part of 12 § shall be defrayed by the person who, in any particular case, conducts the radiologic work or applied for license therefore or for possession of radioactive substance.

14 §.

Persons, who unlawfully conduct radiologic work or possess radioactive substance, shall be punished by fine.

The same applies in the case where a person who, with proper license, conducts radiologic work or possesses radioactive substance, fails to observe his obligations according to this Act or the instructions issued on the basis of the same, or in application or in respect of circumstances in which it is incumbent upon him to give information, knowingly gives false or incomplete information.

A person who is sentenced for misdemeanour as considered in the first part of this paragraph, shall also be compelled to pay the charges as stated in part 1 of 13 §, for the

time for which such charge should have been paid but was not; however, such charge may not be retrogressive for a period longer than two years from the day action was brought.

Fines which are inflicted according to this paragraph accrue to the State.

15 §.

In radiologic work conducted with proper license by the State or Local Authority the director of the work shall be responsible for the observance of obligations according to this Act.

16 §.

If a supervisor has issued instruction according to the 3rd part of 7 §, complaint may be presented to the Royal Medical Board within fourteen days from the day notice was given. At the issuance of instruction, it shall be stated what procedure the person wishing to present such complaint must observe.

Concerning decisions of the Royal Medical Board according to this Act appeal may be presented to the King within the time which is established for the appeal of decisions by administrative authorities and government offices.

When license according to this law is revoked or decree issued that an establishment for radiologic work shall discontinue operations, the Royal Medical Board has the right to decree that the decision shall be put into execution without hindrance of appeal being lodged.

When the Act was drawn up, there was much uncertainty as to how its application should be limited. It has, however, proved to be fortunate that it was decided to set the lower voltage limit for establishments affected by this Act as low as 5,000 volts, since in work with soft roentgen radiation more or less severe radiation injuries arise more often than was expected when the Act was drawn up. The Act is also effective now for »grenz ray» (Bucky) therapy and for all such roentgen spectroscopic and crystallographic work in which there is any possibility for radiation in any appreciable degree to emanate from the apparatus. Concerning the quantities of radioactive substances which come under this Act the Royal Medical Board, at the suggestion of the Institute of Radiophysics has, after minor alterations, made the following proclamation, which also proved to be very useful:

Renewed proclamation of the Royal Medical Board concerning determination of the quantity of radioactive substance to which the Act of June 6, 1941 (No. 334) concerning supervision of radiologic work etc., shall be applicable.

(SFS 886/1941)

The Royal Medical Board hereby notifies that the Board by virtue of the regulations in 1 § of the Act of June 6, 1941 (No. 334), concerning supervision of radiologic work etc., and in accordance with a proposal made by R. Sievert, the director of the Institute of Radiophysics, to repeal the Board's proclamation in the matter of 26. June, 1941, has established the following quantity of radioactive substance to which the Act mentioned shall be applicable.

For radioactive substance, which, for use or storage, is permanently enclosed in a gastight container in such a way that mainly only gamma radiation can emerge: for radium compounds, a quantity containing more than one milligram radium element or, with other radioactive substances, the quantity which, with respect to the ionization effect of the gamma radiation in air, corresponds to more than one milligram radium element in equilibrium with its disintegration products;

for radioactive substance which for use or storage is not permanently enclosed in a gastight container in such a way that mainly only gamma radiation can emerge: for radium compounds, a quantity containing more than 0.1 milligram radium element or, with other radioactive substances, the quantity which, with respect to the ionization effect of the beta and gamma radiation in air, corresponds to more than 0.1 milligram radium element in equilibrium with its disintegration products, and

for radioactive substance which for use or storage is intended to be introduced or unintentionally can enter into the body of persons who are treated with the substance or work with the same or are otherwise present in the vicinity: for radium compounds, a quantity containing more than 0.01 milligram radium element, or, with other radioactive substances, the quantity, which, with respect to the ionization effect of radiation in air, corresponds to more than 0.01 milligram radium element in equilibrium with its disintegration products.

Estimation or measurement of that quantity of radioactive substance which, in the above cases, shall be considered to correspond to the quantities given in milligrams radium element, shall be done with the due consideration to the risk of injurious effects from the rays emitted by the substance.

Radioactive substances are excepted from the Act, however, which are of so slight concentration that the aforementioned quantities stated for various cases are not contained in one kilogram of the substance. For substances with shorter half-life than one month, the law is effective for quantities which, after multiplication by the number which represents the half-life, expressed in months, exceed the aforementioned quantities stated for various cases.

For radioactive substance which is possessed for instructional or scientific purposes by secondary schools, institutions of higher education, or government supported research institutions, the law is applicable only to quantities which exceed 10 times the aforementioned quantities.

When the legislation was drafted in 1939, a number of radiation risks were neglected, which have later became topical through the development of nuclear physics. This is especially true in the case of neutrons, electron rays and ion rays of high energy. However, these rays are often accompanied by γ-radiation, and therefore devices for their production are considered to come under the Act as a rule. Such apparatuses have hitherto, practically without exception, been used for scientific purposes with no profit motive and are therefore free of license-fee (see page 209). Because of this condition and the fact that the Institute of Radiophysics is in close co-operation with all research institutions concerned, the incompleteness of the law in the respect mentioned here has not yet caused any disadvantages.

The forms established by the Medical Board for license applications have the following wording:

(Application is to be presented to the Royal Medical Board in three copies.)

Application

for license to conduct radiologic work, which includes use of roentgen rays
(§ 2 of the Act of June 6, 1941, No. 334).

To the Royal Medical Board.

With reference to the information on the reverse side of the page, the undersigned hereby petitions for license to conduct radiologic work which includes the use of roentgen rays for the following purpose:[1]

roentgen diagnostics (medical, odontologic, veterinary), roentgen treatment (medical, odontologic, veterinary), scientific purpose, technical purpose, instructional purpose.

..... , ... 19....
city date

Recommendation of the Institute of Radiophysics

.....

Stockholm, ... 19....
date

License

In consequence of the above application, the Royal Medical Board herewith issues permission for .....
..... to conduct radiologic work, concerning .....
..... provided that the conditions in the above recommendation of the Institute of Radiophysics are fulfilled.

For the Royal Medical Board:

Stamp

Stockholm, ... 19....
date

.....

Information required regarding application for license to conduct radiologic work.

1. Situation of place of work and nature of work premises (with large establishments, a draft of the plans should be attached if possible):

   Address: Tel. No.

   Location in the building:

   Size of premises (number of rooms for different purposes, height of rooms, floor area, etc.):

   Permanent radiation protection arrangements (in walls, floor, ceiling, etc.):

[1] Purposes which do not apply shall be crossed out.

2. Roentgen apparatus: Make ..... Type ..... Is there complete high tension protection?.....
Appurtenant roentgen tubes: Make ..... Type ..... Highest voltage KV ..... Highest milliamperage.....

3. Additional important equipment and aids, intended for use in the work:

Equipment (Fluoroscopic stand, trochoscope, skull table, etc.)	Manufacturer and year of delivery	Additional information which could be of importance in the consideration of radiation protection.
.....		

Additional radiation protection arrangements: ..... unattached protective screens, ... pairs of protective gloves, ... protective aprons.

4. Director of this work will be:
Full name: Year of birth:
Address: Tel. No.
For the work in question he has the following qualifications:

5. Number of persons who are expected to be engaged in the work:
Doctors ....., Nurses ....., Assistants .....,
Engineers ....., Foremen ....., Workers .....,

6. Additional circumstances, which could be considered of importance for a decision on the application:

(Application is to be presented to the Royal Medical Board in three copies.)

Application

for license to conduct radiologic work, which includes the use of radioactive substances and for possession of such]

(§ 2 of the Act of June 6, 1941, No. 334).

To the Royal Medical Board.

With reference to the information on the reverse side of the page, the undersigned hereby petitions for license to conduct radiologic work which includes the use of radioactive substance for the following purpose[1]: treatment (medical, odontologic, veterinary), scientific purpose, technical purpose, instructional purpose,
to possess radioactive substance to a quantity of

..... 19 ....
city date

Recommendation of the Institute of Radiophysics.

.....

Stockholm ..... 19....
date

[1] Purposes which do not apply shall be crossed out.

License

In consequence of the above application, the Royal Medical Board herewith issues permission for .....
..... to conduct radiologic work, concerning .....
..... and to possess radioactive substance, provided that the conditions in the above recommendation of the Institute of Radiophysics are fulfilled.

For the Royal Medical Board:

Stamp
Stockholm ..... 19 ....
date

Information required regarding application for license to conduct radiologic work and to possess radioactive substance

1. Situation of place of work and nature of work premises (with large establishments, a draft of the plans should be attached if possible):
   Address: Tel. No.
   Location in the building:
2. Situation and nature of storage place:
3. Quantity of radioactive substance in permanently sealed gastight containers:..... mg. radium, distributed in ..... preparations, ... mg. mesothorium and/or radiothorium distributed in ..... preparations, ...
4. Quantity of radioactive substance, which is not permanently enclosed in gastight containers ..... mg. radium, ...
   Is the substance intended for external use? .....
   Is the substance intended for internal use? .....
   Is the substance stored or used in such manner that it could unintentionally be introduced into the body of persons who are treated or work with the substance or are present in the vicinity? .....
5. Important equipment and aids, intended for use in the work or in the storage:
6. Director for the work will be (not to be filled in on application which only concerns possession):
   Full name: Year of birth:
   Address: Tel. No.
   For the work in question he has the following qualifications:
7. Number of persons who are expected to be engaged in the work:
   Doctors ..... Nurses ..... Assistants .....
   Engineers ..... Foremen ..... Workers .....
8. Additional circumstances, which could be considered of importance for a decision on the application:

When a more extensive change in an establishment takes place, or there is significant increase in the quantity of the radioactive substance used a notification is made on a form with the following wording:

(Notification is to be presented to the Royal Medical Board in three copies.)

Notification

of change of radiologic work which includes the use of roentgen rays, and for which a license has been issued by the Royal Medical Board

(§ 4 of the Act of June 6, 1941, No. 334).

To the Royal Medical Board.

Changes, stated on the reverse side of the page, in respect to the roentgen establishment mentioned there, are herewith reported.

..... 19....
city date

Recommendation of the Institute of Radiophysics

.....

Stockholm, ... 19....
date

Information required concerning notification of changes

1. Situation of place of work:
2. License issued by the Royal Medical Board on .....
3. Moving of the work to other premises or important reconstruction of the premises for which license is effective:
4. Exchange or appreciable change of roentgen apparatus, roentgen tube or rectifying valve (increase in voltage should be reported in cases where it exceeds 20 KV; exchange of roentgen tube or valve for another of the same or similar type for the same or lower load need not be reported):
5. Exchange of or appreciable change of important equipment and aids used in the work:
6. The former director has been replaced by:
   Full name: Year of birth:
   Address: Tel. No.
   For the work in question he has the following qualifications:
7. Additional changes, which could be considered of importance for a decision on the continued validity of the license:
8. Work has been discontinued because of ..... from and including .....
   date

(Notification is to be presented to the Royal Medical Board in three copies.)

Notification

of change of radiologic work, including use of radioactive substance or possession of such substance for which work or possession a license has been issued by the Royal Medical Board

(§ 4 of the Act of June 6, 1941, No. 334).

To the Royal Medical Board.

Changes, stated on the reverse side of the page in respect to work with and/or storage of radioactive substance are herewith reported.

..... 19....
city date

Recommendation of the Institute of Radiophysics

.....

Stockholm ..... 19....
date

Information required concerning notification of changes

1. Situation of work and/or storage place.
2. License issued by the Royal Medical Board on: .....
3. Moving of the work to other premises or important alterations in the premises for which the license is effective:
4. Increase in quantity of radioactive substance:
5. Change in manner of mounting and/or storage:
6. The former director has been replaced by:
   Full name: Year of birth:
   Address: Tel. No.
   For the work in question he has the following qualifications:
7. Additional changes, which could be considered of importance for a decision on the continued validity of the license:
8. Work has been discontinued because of ..... from and including .....
   date
9. The quantity of radioactive substance has or has been decreased to:

The following instructions, after changes in 1942 and 1945, are effective for the supervisory activities of the Institute of Radiophysics:

Instruction

for activities conducted by the Institute af Radiophysics, as far as they concern the Act on supervision of radiologic work etc.

(M. F. 136/41, 122/42 and 108/45)

1 §.

The Institute of Radiophysics has the duty, inter alia, of exercising supervision of the observance of the Act on supervision of radiologic work etc., and of instructions authorized by this Act, the Institute being under the supervision and guidance of the Royal Medical Board.

In this respect the Institute is instructed especially:

to obtain accurate knowledge of working conditions within the sphere of its activities and closely to follow the developments in radiation protection and the related research field;

to make recommendations, on request of the Royal Medical Board, concerning applications for license to conduct radiologic work or possess radioactive substance, and concerning notifications of changes which have occurred after the issuance of such license;

to perform inspections of establishments for radiologic work or storage places for radioactive substance and also to give attention to the working methods used;

to consult with the National Board of Commerce on matters specified in the aforementioned Act which also concern application of instructions which have been issued concerning the construction and maintenance of power current establishments;

to perform investigations of material and devices intended for protection against roentgen-rays and radiation from radioactive preparations, and to perform radioactivity determinations and mounting of radioactive preparations, to the extent which is consistent with the rest of the duties of the Institute;

to assist the Royal Medical Board with the working out of instructions for the prevention of injury through effect of roentgen-rays, or radioactive substance, and to perform the investigations which might be necessary in connection therewith; and

to take up scientific research projects in the fields of radiophysics and biophysics which are of importance to the activities of the Institute, to the extent permitted by available resources.

At the laboratory, opportunity for scientific research, to the extent it is expedient, should be provided for the scientists employed there.

2 §.

The Institute includes:

a) a department for control of roentgen establishments for diagnostics and technical and scientific purposes, etc.;

b) a department for control of roentgen treatment establishments; and

c) a department for control of protection arrangements for radioactive preparations and for testing and mounting such preparations.

3 §.

Before the Institute makes a recommendation concerning application for license to conduct radiologic work or possess radioactive substance, or concerning notification of change which has occurred after the issue of such license, if the Royal Medical Board so requests or the Institute otherwise finds it necessary inspection of work or storage premises shall be made by the Institute.

4 §.

Supervision of radiologic work and of storage of radioactive substance shall be exercised through periodic inspections, which, in the case of the different establishments, shall be made in the following manner:

Establishments for:	Frequency of inspection:[1]
a) medical and veterinary roentgen diagnostics	once every third year
b) dental roentgen diagnostics	once every sixth year
c) roentgen investigations for technical purposes	
large establishments	once every year
small establisments	when necessary
d) roentgen treatment	twice every year
e) work with, and storage in connection therewith, of radioactive substance, provided the combined supply exceeds 100 mg. radium element	once every year
f) other radiologic work, without or in connection with storage of radioactive substance, or for such storage alone	when necessary

The interval between inspections performed for recommendations according to § 3, and ensuing periodic inspections, may be modified to suit the established travel programme of the supervisor concerned.

Establishments, where appreciable risk of injury appears to exist, or where incipient injuries have been observed, shall be subjected to more frequent inspections and, if necessary, to more thorough investigations also. If more serious radiation injury has arisen at an establishment, it shall be subject to extra inspection.

5 §.

Inspection shall concern supervision of establishments and work premises being constructed in accordance with valid instructions and, also, of the work being so conducted that the greatest possible security is obtained against the occurrence of injury through effect of roentgen-ray or radiation from radioactive substance, to anyone engaged in the work, or person or animal that is subject to radiologic examination or treatment, or anyone who is casually present on the premises.

The inspection shall include permanently installed and movable radiation protection devices as well as other protective measures used in the work. Tests and investigations shall be undertaken, to the extent needed, to control that protection instructions issued are being properly observed.

Inspection of establishments for roentgen treatment shall also include dosage control designed to establish, with satisfactory accuracy, the physical factors which are of fundamental importance for the actual roentgen treatment and for appropriate use of the establishment.

Observations made at inspection concerning power current danger, which might be considered to call for measures by the State Electricity Inspection Authority, shall be reported to the National Board of Commerce.

The inspections shall be performed in such way as not to disturb more than necessary the course of the work with which the inspection is concerned and must only take place during the usual working hours of the establishment under inspection, except when occasioned by special reasons or when no appreciable inconvenience will be caused thereby.

[1] Before 1945 the frequency of the inspections was:
for a) once every second year
b) once every fourth year.

If the inspection concerns possession of radioactive substance, it shall be seen that the substance is so stored that injury is not caused to anyone through the radiations emanating therefrom.

6 §.

Regular employees of the Institute are employed at the cost of the Karolinska mediko-kirurgiska institutet and the Karolinska sjukhuset as part of the normal establishment, and in addition, as the need arises and in observance of authorized estimates, extra employees, to the number and at the salary that the directorate of Karolinska sjukhuset and the Board of King Gustaf V's Jubilee Fund decide, with regard to available resources.

7 §.

The director is responsible for the work and discipline of the Institute. He is instructed to:

direct and superintend the performance of the work for which the Institute is responsible;

see that inspections, examinations and other commissions are carried out with the promptness that is compatible with the other activities of the Institute;

direct the work of the subordinate personnel and see that they are present at their work for the prescribed daily time;

see that the books and records are kept at the Institute, as prescribed by the Royal Medical Board;

make reports, with assistance of the assistant professors and radiation protection inspectors of the Institute, upon request from the Royal Medical Board; and

render an annual report of the activities of the Institute during the preceeding year prior to the 31st March each year.

8 §.

Regarding performance of recommended inspections or investigations, it devolves upon the director to decide the method, which, after careful investigation, is found to best fulfil the requirements of the science and the purpose of the investigations. In addition, he shall abide by the statutes and instructions, as well as directions of the Royal Medical Board in special cases.

9 §.

In matters on whose treatment he has been called in by the Royal Medical Board, the director shall give information and advice and state his opinion, being entitled, if the Board disagrees, to have his opposing opinion recorded in the minutes of the Royal Medical Board.

The director shall also, on his own initiative, notify the Royal Medical Board on such advances in science within his sphere which, either have great importance to supervision of radiologic work or storage of radioactive substances, or also would seem to occasion official measures from the Board's side, as well as make the recommendations to the Board that he finds appropriate.

10 §.

Department directors are instructed, each for his department:

to be responsible to the director, for the work and discipline within the department and to superintend and direct the work of the personnel, as well as see that they are present at their work for the prescribed daily time;

in the capacity of supervisor and in observance of regulations in § 3—5 to inspect, according to a plan established by the director, places where radiologic work is conducted or where radioactive substance is stored and to perform prescribed examinations there;

when, at such inspections protection instructions, over and above those issued by the Royal Medical Board, are deemed necessary or when instructions issued have not been observed, to report the circumstances to the director of the Institute and to the Royal Medical Board and/or personally to issue further instructions which appear necessary, when observance of them is not accompanied by great expense or inconvenience;

when special circumstances demand that an establishment for radiologic work discontinue operations or that a license be rescinded, to report such circumstances to the director and the Royal Medical Board immediately;

likewise to perform the additional investigations and work, at or outside the Institute, which are entrusted to him on its account, as well as to travel to other districts for such purpose, on instruction from the director;

on instruction from the director to prepare matters within the sphere of activities of the Institute, which have been submitted to the Institute for report:

to answer letters and official requests for information received by the Institute, to the extent decided by the director, insofar as they concern activities of his department;

closely to follow the scientific development within the sphere of activity of the department and, when he finds cause, present suggestions to the director concerning the work of the department; and

also to take part in the work of other departments of the Institute as the need arises, according to the instructions of the director, especially in respect of such service trips in which the travel expenses could be decreased hereby.

11 §.

The director of the department for control of roentgen treatment establishments and the director of the department for control of protection arrangements for radioactive preparations and testing and mounting of such preparations, shall each perform approximately half of the service trips and tasks connected therewith, which fall within the field of work of both departments.

12 §.

The assistant professor in radio-biology and chemistry is instructed:

to perform the investigations and tasks within or outside the Institute, which are entrusted to him on its account;

on instruction from the director to prepare matters belonging to his sphere of activities, which are submitted to the Institute for report; and

closely to follow the scientific development within his sphere of activities, and when he thinks fit, to present suggestions to the director concerning the work of the Institute.

13 §.

The chief radiation protection inspector is instructed:

under guidance of the director of the department for control of roentgen establishments for diagnostics as well as technical and scientific purposes, etc., to participate in the work of the department and, on direction from the departmental director, indepen-

dently perform inspections to the extent determined by the director of the Institute;

when he serves at the Institute during the absence of the departmental director to fulfil the latter's duties to the extent that the latter decides is compatible with the other functions of the inspector; and

also to observe the instructions issued by the director of the Institute or the departmental director.

14 §.

The radiation protection inspector is instructed:

under guidance of the director of the department for control of roentgen establishments for diagnostics or technical and scientific purposes, etc., to participate in the work of the department and, on instructions from the departmental director or chief radiation protection inspector independently perform inspections, to the extent determined by the director of the Institute; and

also to observe the instructions issued by the director of the Institute, the departmental director or the chief radiation protection inspector.

15 §.

The assistant is instructed:

to assist in inspections and the work connected therewith; and

to the extent determined by the director, to assist in other work of the Institute.

16 §.

The medical expert is instructed:

in consultation with the director or departmental directors, to collate the information contained in medical certificates received by the Institute and other reports concerning persons engaged in radiologic work;

to study medical certificates received by the Institute and present such suggestions and recommendations which these might occasion;

when suspicion of radiation injury exists to examine the case in more detail and participate in the investigation into the matter, which may prove necessary; and

on request from the director, also to report on other medical questions arising in connection with the supervisory activities.

17 §.

Persons who have or have had connection with supervision of the observance of the Act concerning supervision of radiologic work etc., are forbidden to disclose professional secrets and neither must they, where it is not in the interest of the Institute, reveal operating arrangements or business conditions at the place of work or storage place when the person has or has had such connection.

18 §.

When the activities conducted by the Institute are not covered by this Instruction, the regulations for the Karolinska sjukhuset and Serafimerlasarettet are effective.

At every establishment there is an inspection book, in which the representative of the Institute reports what occurred in the inspection and which measures are prescribed concerning radiation protection,

working technique, health control, etc. in order to reduce the risks of radiation injuries in the work.

It has proved to be necessary, with reference to the protective devices required in roentgen ray work, to take the scale on which the work is done into consideration. This is especially true with roentgen diagnostics, for which the following norms have been laid down:

Nature of premises	Radiologic work allowed expressed as the sum of the number of fluoroscopy minutes and of photographic exposures
Spacious premises with adequate protection devices	Unlimited
Spacious premises with less adequate protection	120 per week
Confined space but comparatively good protection	60 » »
Confined space and relatively poor protection	30 » »

As a large number of those who are occupied with roentgen ray work to a great degree lack the knowledge of the characteristics of the rays and their physiologic effects, every roentgen department receives a number of very brief and simple instructions which are to be distributed to all who take part in the radiologic work. The instructions have been given the form of a memorandum with following wording:

Memorandum
to directors of roentgen ray work and persons engaged in roentgen ray work.

Because of the relatively large number of radiation injuries, which annually come to the knowledge of the Institute of Radiophysics, the Institute has felt compelled to issue the following advice and instructions over and above the injunctions and instructions given at or in conjunction with its inspections. These may be disregarded *only* in medical and odontologic roentgen ray work in the *exceptional cases* in which the welfare of the patient and the type of work make it necessary.

Directors for roentgen ray work shall see that all persons engaged in the work are familiar with the instructions given, and see that they are observed.

Employees shall use available protection devices and in other respects follow the instructions given to prevent sickness or accident in the work.

Advice and instructions should be posted clearly visible to the roentgen personnel.

Stockholm, April, 1948.

Institute of Radiophysics

Address: Stockholm 60
Tel.: »Karolinska sjukhuset».

Always remember with roentgen ray work:

that every object irradiated by roentgen rays, emits roentgen radiation in its turn,
that you cannot determine directly by your senses when or how much you expose yourself to roentgen radiation,
that repeated weak irradiations as well as a few minutes, or even seconds, of strong irradiation *can* cause non-healing injuries,
that *every* roentgen ray irradiation can occasion permanent changes in the system,

that roentgen ray injuries sometimes first appear several years after the irradiation,
that there are roentgen ray injuries which you do not notice or recognize as such yourself, but which can injuriously affect your general condition of health and lower your resistance to infections,
that failure to follow the instructions issued, may result in reduced compensation for sickness incurred in work (§ 25 of the Accident Insurance Act).

The advice and instructions issued have been originated for your own protection first and foremost, and are intended to eliminate the risks of sickness which accompany careless roentgen ray work. Where there is difficulty in following them or doubt prevails about their application, the Institute of Radiophysics shall be asked for advice.

Observe the following with roentgen ray work:

Do not expose yourself, persons participating in the work, or other persons to the direct radiation from the roentgen tube. — Make sure that this radiation will fall only on effective radiation protection screens or have such direction that no one can be inadvertently exposed to it.
Avoid staying, without protection, in the vicinity of patient or object being roentgen ray irradiated.
In the *exceptional cases*, where the welfare of the patient *and* the type of investigation unavoidably require that the patient, cassette or any other object be held during roentgen ray work, try then to use a person who is not exposed to radiation otherwise. See that such assistants are protected as well as possible with available radiation protection devices. In addition, distribute such work so that each person participating therein receives the least possible irradiation.
Use the smallest possible quantity of radiation in roentgen ray examination. Close the diaphragm as much as possible. Do not use less than 35 cm target—skin distance except for odontologic exposure. Wait till your eyes are well adapted before fluoroscoping of a patient, use the shortest possible fluoroscopic time and lowest possible intensity of current — if possible, not higher than 3 MA.
Roentgen ray apparatus or its appurtenant devices must not be used for purposes for which they in respect to the radiation risks are obviously not suitable. Do not use apparatus for fluoroscopy which is not provided with attached fluoroscopic screen, with necessary protection devices and with satisfactory diaphragm equipment.

Report immediately to the Institute of Radiophysics if it is feared that radiation injury has occurred.

The undersigned herewith acknowledge having read the above instructions

Year	Date	Name (write legibly)
.....	.....	.....

The general instructions which are to be drawn up according to § 10 of the Act have not yet been confirmed. It has proved unusually difficult, notwithstanding almost ten years' experience in the field of radiation protection, to arrive at definite instructions which fulfil the necessary demands for effectivity, flexibility and adaptability. However, a final proposal for instructions for roentgen work is to be found in this issue (page 364). It was drawn up by WAHLBERG after thorough

discussion with the rest of the staff of the Institute of Radiophysics and with representatives of the radiologists.

Regarding medical examination and inspection required by § 12 of the Act, the Royal Medical Board has issued a decree with regulations concerning medical certificates at the time of employment of personnel in radiologic work and for annual medical inspection of those engaged in such work.

The wording of the certificates is as follows:

Certificate of medical examination, as required by the first part of § 12 of the Act of June 6, 1941, about supervision of radiologic work etc. (SFS No. 334.)

Full name:

Date of birth:

Children: Number of children and ages:

For women: Menstruation, regular? Type: days / weeks

Married: For how long: Unmarried:

Has the applicant suffered from anaemia or other blood disease?

Has the applicant suffered from hypersensitivity to sunlight, eczema, psoriasis, other dermopathy or burn injury?

Type, site and course of such dermopathy or injury:

Has the applicant suffered from other serious disease?

Does the applicant consider himself to be at present completely healthy?

Has the applicant previously performed radiologic work or been responsible for radioactive substance?

In such case, during which period?

Has this been accompanied by any injury to the condition of health, for example, blood changes or skin changes on hands or elsewhere?

In such case, when did these changes begin to appear?

Has the applicant a healthy appearance?

Is the applicant well-nourished?

Color of skin:

Does the examination show any heart-disease?

Does the examination show any lung-disease?

Does the urine contain albumin or sugar?

Is the skin on the hands and elsewhere normal?

If such is not the case, describe in detail the skin changes:

Blood picture: Haemoglobin: Method used? Corrected / uncorrected value

Red cells: White cells:

Differential count: Neutrophilic leucocytes: of which are rod forms, segmented leucocytes.

Eosinophils: Basophils: Lymphocytes: Monocytes:

Do you consider the applicant to be completely healthy at the present time and without predisposition to disease?

.....
signed

..... 19....
city date

Not more than 15 crowns is to be paid for this certificate, according to the decree of His Royal Majesty, June 28, 1941.

— —

Instruction for issuance of certificates concerning medical examinations, as referred to in the first part of § 12 of the Act of June 6, 1941, concerning supervision of radiologic work etc.

The first part of the paragraph in question reads: »In radiologic work, no other persons must be employed than those who, on medical examination, are found not to show sickness or weakness which may be considered to make them especially subject to the health risks connected with the work.»

Markedly asthenic and delicate persons and those who suffer from anaemia or other blood disease, are unfit for radiologic work as a rule. The weak general radiation on the body to which the operator is subject can gradually lead to a general injury to the health even with healthy persons. Such injury is first and most distinctly recognizable, as a rule, by blood examination, in the form of anaemia or leucopenia (relative lymphocytosis).[1]

Skin injuries are the most common of more localized radiation injuries. The skin of the hands is most exposed to irradiation during the work. In certain cases, the skin on the arms, face, chest and abdomen are also especially exposed. It is commonly stated in the literature that persons who suffer from metabolic diseases and endocrine disorders, in particular Morbus Basedowi, have a skin especially sensitive to roentgen and radium radiations. People who suffer from hypersensitivity to sunlight and eczema (especially on the hands) are probably unfit for radiologic work. Psoriasis may imply somewhat increased risk of radiation injury to the skin. Burn injuries are especially mentioned on the form, because chronic ulcers and skin cancer may arise in scars following burn injuries in the same way as in radium or roentgen ray injured skin.

Ovaries and testicles are particularly radiation-sensitive organs, and sterility may sometimes arise as a result of radiologic work. Even if it is possible that certain forms of menstrual disorders may predispose toward a radiation injury to the ovary, such disorders can hardly be considered as an obstacle to employment in radiologic work, as a rule. It is, however, valuable for an eventual future opinion, if such disorders, as well as criteria for the existence of sterility, are registered at the actual time of employment.

The points in the form which are not directly occasioned by the aforementioned special considerations of the risk of radiation injury, such as, for example, information about heart, lungs, urine, are intended to complete the medical certificates so that a special so-called certificate of health shall not be necessary at the same time in all cases. If the person who seeks employment in radiologic work is found to have, for example, slight vitium or signs of having had pleurisy, this is not necessarily in itself an obstacle to employment in radiologic work. In such cases, the capacity for work should be judged on the usual grounds with respect to the type of work and regardless of radiation effect.

[1] This is no longer in full accordance with the experience gained in the supervisory work. (See p. 250, HELDE, 112, and NORDENSON, 109.)

As blood examination in this connection is of specially great significance, it is important that it be performed, if possible, by a haematologist, a specialist in internal medicine or other person who is continuously engaged in blood examinations including also differential counting of the white blood cells.

Before January 15th each year, the person in charge of radiologic work shall send in to the Institute of Radiophysics, the Karolinska sjukhuset, Stockholm 60, all medical certificates according to the form on the reverse side of this page, or certified copies of the same, for the persons who during the preceding year obtained employment in radiologic work or work involving responsibility for radioactive substance.

Certificate of inspection, as required by the second part of § 12 of the Act of June 6, 1941, concerning supervision of radiologic work etc. (SFS No. 334.)

Full name:

Date of birth:

Employed with / at In the capacity of:

Has participated in radiologic work for years.

Healthy appearance:

Radiation changes in skin on hands or elsewhere? (Brief description if changes are found. State whether improvement or deterioration has taken place since preceding inspection.)

Blood picture: Haemoglobin: Method used: Corrected / Uncorrected value

Red cells: White cells:

Differential count: Neutrophilic leucocytes: of which are rod forms, segmented leucocytes.

Eosinophils: Basophils: Lymphocytes: Monocytes:

..... 19....
city date

.....
signature of doctor

Not more than 10 crowns are to be paid for this certificate, according to the decree of His Royal Majesty, June 28, 1941.

Instructions for issuance of certificates concerning inspection, as referred to in the second part of § 12 of the Act of June 6, 1941, concerning supervision of radiologic work, etc.

The second part of the paragraph in question reads: »Persons employed in radiologic work shall periodically undergo inspection concerning their condition of health.»

According to Royal Proclamation on June 28, 1941 (No. 640), the aforementioned investigation shall be made once a year.

Before the 15th of March each year, the person in charge of radiologic work shall send in to the Institute of Radiophysics, the Karolinska sjukhuset, Stockholm 60, all medical certificates according to the form on the reverse side of this page, or certified copies

of the same, for each of the persons engaged in radiologic work under him. All of the above-mentioned medical certificates should be made out during February of the year during which they are sent in to the Institute named.

Concerning the question as to which persons should undergo the aforementioned investigation, see the circular drawn up by the Institute of Radiophysics, Dec. 18, 1941, which also concerns the medical examination mentioned in part one of § 12 of the aforementioned Act. This circular may be obtained on request from the Institute of Radiophysics, The Karolinska sjukhuset, Stockholm 60.

However, during recent years, the opinion has been reached that the Institute of Radiophysics must be authorized to prescribe blood examination in such cases where special radiation risks are feared or where there are reasons for repeating the examinations more often than usual, and also that the differential counting of blood smears must be done centrally at the Institute of Radiophysics. It is only if the same personnel perform all blood counts, that comparable results can be depended upon. A laboratory for blood investigations has therefore been established at the Institute, and as soon as possible all differential counts for radiologic supervisory activities will be made there. The following regulations on this matter are at present in effect:

Royal Proclamation of June 28, 1941, and Dec. 9, 1949.

(SFS 640/1941 and 639/1949.)

1 §.

Certificates of medical examinations according to part 1, § 12, of the Act on supervision of radiologic work, etc., shall be made out according to regulations given by the Royal Medical Board and on forms approved by that Board.

2 §.

Inspection mentioned in the second part of § 12 of the Act mentioned shall be done once a year where supplementary inspection, according to the following, is not required. At inspection, a blood investigation shall, inter alia, be made and a differential count of white corpuscles be executed.

If, at inspection according to the above, there arises suspicion of radiation injury, the Institute of Radiophysics is authorized to prescribe a supplementary inspection if further investigation is deemed necessary. Such inspection may be limited to comprise only blood examination.

Further instructions on inspection are issued by the Royal Medical Board.

Circular of the Royal Medical Board of Jan. 22, 1949.

(M. F. 2/1949.)

The Royal Medical Board has this day directed that certificates of medical examination, as referred to in the first part of § 12 of the Act of June 6, 1941 (No. 334), con-

cerning supervision of radiologic work etc., and also certificates of inspection as referred to in part two of § 12 of the Act mentioned shall henceforth and until further notice be submitted to the Institute of Radiophysics together with two unstained and unfixed blood smears enclosed in a special envelope, clearly marked with the individual's name and place of work. The smears, which are to be when necessary subjected to examination by a haematologist, shall be made the same day as the medical examination, or respectively, inspection takes place.

Concerning the inspection of establishments for radiologic work, the following may be said:

At the first inspection of an establishment, a sketch with approximate dimensions is drawn up of the premises, with information also about the use of adjacent premises. The protective walls present, the protection that may be afforded by floor and ceiling, as well as attached and mobile protective devices appurtenant to the apparatus, are noted. The placement of equipment and auxiliary apparatus is marked and their type noted. Significant distances, radiation protection and direction of rays are examined and, as a rule, radiation measurements are made. The working technique used is studied thoroughly, especially in such establishments (for example, childrens' hospitals, asylums and industrial establishments for manufacture of roentgen tubes) where, because of the type of work, the risks are dependent to a large degree upon how the work is done.

At the subsequent inspections, recent experience that is continuously emerging from the inspection activities is applied and the working technique is subject to a renewed control. Often the apparatus or the type of work has been changed or its scope greatly increased, whereby new risks may have appeared. Radiation measurements are made when needed, either by direct-reading instruments carried by the inspectors, or through remittance of condenser chambers by mail. Direct measurements of the radiation dose, which those engaged in radiologic work are exposed to, have proved to be of limited significance, however, as it is not yet possible to make them on a sufficiently large scale. New methods for large-scale measurements are under preparation.

An important factor in the supervisory work is formed by the »tolerance dose», which is the basis used when appraising whether a given radiological work can be looked upon as injurious to health or not. In the author's opinion it is more correct to exchange the »tolerance dose» (the limit beyond which noticeable biological effects appear as a rule) for the »safety dose» which has been selected at so low a level that the probability is very slight that radiation effects of known nature can arise unless this limit is very greatly exceeded. After more than 20 years work within the field of radiation protection, the Institute of Radiophysics has reached the following conclusions:

1) It is as a rule impossible to obtain necessary reliability in radiation measurements on persons working with roentgen rays, and in many cases this applies also where work with radioactive substances is concerned. For reasons easily explained, very big doses — especially in roentgen diagnostics — can accidentally be received even in apparently well protected establishments and careful working technique.

2) Regarding skin reactions and blood changes and especially the genetic influences of ionizing radiation, available information does not allow any reliable conclusions to be drawn (not even within a margin of 1: 5) regarding the radiation-doses that can be regarded to be wholly harmless. It is also apparent that the natural need for a safety margin, owing to conditions as stated above, has been often overlooked, and the Swedish safety dose is sometimes compared to the tolerance dose in U. S. A. and England without mentioning the fact that we in Sweden estimate our dose to be 5—10 times less than that which we regard as likely to cause considerable physiological effects.[1]

As no reliable foundation for the establishing of biological tolerance doses is available the Institute of Radiophysics has reasoned as follows: *It seems to be obvious that a total irradiation of the body with doses of between 1—10 r per week, or 50—500 r per year, would cause injurious effects.* We do not know if even smaller doses cannot involve danger. However many different kinds of biological actions are observed at much lower dosages. Also, we are not aware as to what extent the effects depend upon whether the dose is given in a few short and intense irradiations, or in less intense irradiations during a longer period of time. Our knowledge as to the significance to the state of health of the observed blood changes is, to say the least, imperfect. Larger and larger groups of the population are being exposed to ionizing radiation in hospitals and in industrial and scientific work. There are therefore many reasons for caution.

This is one side of the matter. The other is that in most cases it would be possible *at a comparatively slight cost and without any serious hindrance to the rational pursuance of the work to prevent that a dose of ca. 0.1 r per week is exceeded.* Consequently, radiation protection and working techniques should be so designed that this dose is not exceeded in *normal radiological work.* Furthermore, this would supply a safety margin reducing the risk when accidentally higher doses are received. Besides, the advantage is also gained that a measured higher dose will let a defect in the protection measures or working technique appear before any risk of more serious injuries occurs.

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[1] *e. g.* see ELLIS, F.: Brit. Journ. Rad. 23, p. 28, 1950.

It is a different matter in those cases when conditions are such that as low *a safety dose as 0.1 r per week is incompatible with the nature of the work*. Here larger doses must be permitted, but the *control must then also be stricter and above all continuous, both as regards radiation investigations of different kinds and regarding health control.*

In this connection it may be mentioned that in Sweden a prolonged vacation is granted to persons who are, in their work, exposed to roentgen rays or radiation from radioactive substances to a degree implying a significant risk for radiation injury. Such a vacation was given to certain State employees more than 10 years ago, who receive a vacation of up to 60 days a year after 5 years' radiologic work and up to 90 days after 10 years. Those privately or municipally employed in radiologic work have, by an Act of 1946, a similarly prolonged vacation, though the limit is here 6 weeks. The conditions of validity, however, were not framed quite adequately in the Act which is therefore probably soon to be amended. There is thus no reason to give more detailed information about this matter.

Concerning the number of the supervisory personnel and the scope of supervisory activities, some facts will be given in the next section of this article and in special reports in this volume by BENNER (p. 281), LARSSON (p. 357), and THORÆUS (p. 253). In the articles mentioned, some experiences from the supervisory activities will also be found.

Concerning organizational details however the following may be said here:

The supervisory work is assigned to three departments (see pages 203 and 217). In order to arrive at as great continuity as possible in the control work, all of the more important supervisory matters are discussed under the chairmanship of the Chief of the Institute, in the presence of all supervisors. The supervisor who made the inspection or investigation in question reports the case. The Chief has the right of final decision concerning recommendations to the Royal Medical Board in supervisory matters but, except in very special cases, follows the supervisors' advice. Careful minutes are kept of these meetings. At certain of them the medical expert also participates, when the cases which present injuries or other radiation effects are discussed, and decisions are made as to which measures should be adopted.

The authority of final decision rests with the Royal Medical Board which, however, in practically all cases follows the recommendations of the Institute of Radiophysics.

In especially complicated cases where uncertainty prevails, or where the consequences of the matter are or may become considerable, the Institute of Radiophysics petitions for a conference with the Royal Medical Board, or the Royal Medical Board requests a meeting. On

these occasions, as a rule, one or more medical specialists, usually belonging to the scientific council of the Royal Medical Board, also participate.

Some information may also be given here about the economic organization of the supervisory activities.

With the origin of the Radiation Protection Act, a tariff was established for the legally prescribed inspections. It is not surprising that a certain opposition arose from many quarters on the grounds that the supervision, although obligatory, was accompanied by a charge to the owners of establishments. Moreover, it was believed that the actual inspections were the only work the Institute had to perform in the supervisory activities, and the extensive work at the Institute which accompanied them was often overlooked.

When, as the supervisory activity grew so rapidly that it threatened to smother the other activities of the Institute completely, the personnel was increased in 1945 and simultaneously the frequency of inspections was reduced (see note on page 218) and also the tariff was changed in such a way that the charges for inspection were replaced by annual license fees according to the following scale of charges:

Regulations concerning certain fees according to § 13 of the Act of June 6, 1941 (No. 334) concerning supervision of radiologic work etc.
(SFS 471/45.)

1 §.

Charges as indicated in the first part of § 13 of the Act concerning supervision of radiologic work etc., shall be paid in advance and, when for the entire calendar year, are payable in the amounts stated in § 2 of this proclamation. If the obligation to pay the charge arises during the calendar year, in that year the charge is payable in an amount corresponding to that part of the charge for the entire year which accrues to that calendar quarter during which the obligation arose, and to that or those calendar quarters, during which obligation for charges otherwise exists.

2 §.

Charges which are the subject of § 1 shall be payable in the following amounts:

A. Roentgen diagnostics etc.	Crowns
a) apparatus for medical and veterinary roentgen diagnostics	50: —
b) apparatus for odontologic roentgen diagnostics	20: —
c) apparatus for roentgen investigations for technical purpose and apparatus used for profit for roentgen investigations for instruction or research purpose	100: —
B. Roentgen treatment.	
d) treatment department with one roentgen tube in use	500: —
e) treatment department with two or more roentgen tubes in use, for the first tube	500: —
for each succeeding tube	300: —

C. Work with and storage of radioactive substance.

f) establishment for work with and, in connection therewith, storage of sealed radium preparation:
for each ten milligrams radium element or part thereof ..... 10:—
however, not more than ..... 100:—
in addition, for each teleradium apparatus or other complicated installation, in which a radium quantity exceeding 500 mg. radium element is used..... 50:—

g) establishment for work with open radium preparations and storage connection therewith:
for each tenth of a mg. radium element or part thereof ..... 5:—
however, not less than ..... 40:—

h) establishment solely for storage of radium:
for each ten mg. radium element, or part thereof ..... 5:—
however, not more than ..... 50:—

Concerning work with or storage of other radioactive substances than radium, their radium equivalent shall be calculated according to principles established by the Royal Medical Board,[1] whereafter the charge is calculated according to f)—h).

If an establishment that is considered under c) and f)—h) is small or if an establishment that is considered under d)—e) is only used to an inconsiderable extent, the director of the Institute of Radiophysics has the right to grant reduction of the charge of up to 50 per cent. Concerning an establisment that is considered under a) and b), the director has the right to grant the same reduction if there are important reasons therefore.

3 §.

Payment for inspection, according to § 5 of the Act concerning supervision of radiologic work etc., as result of application for license, shall be payable in the amount corresponding to the amount prescribed in § 2 of this proclamation for each special case, if the application is not approved. If the application is approved, the inspection shall be free of charge.

4 §.

The charges are collected by the Karolinska sjukhuset. More detailed directions concerning payment of the charges are issued by the Royal Medical Board.

Through the change to license fees from inspection fees and through the personal efforts of the supervisors, the original dislike of the supervisory activities, existing in some quarters, was counteracted and, with few exceptions, the Institute now has exceptionally good cooperation with the persons and institutions which are subject to the radiation protection control.

For additional work which is incumbent upon the Institute, there is a further detailed scale of charges.

[1] See 886/1941 (p. 210 f.).

The income to the Government from radiation protection activity is apparent from table II.

Table II

Survey of the Government's income from the supervisional work of the Institute of Radiophysics.

Fiscal year	1941/42	Sw. cr. 41,077: 60
	1942/43	104,575: —
	1943/44	114,887: 01
	1944/45	127,161: 89
	1945/46	169,476: 77 [1]
	1946/47	130,375: 71
	1947/48	136,916: 20
	1948/49	141,143: 15

When the State took over the Institute of Radiophysics in 1941, the annual income was taken as 90,500: — Swedish crowns.

The income thus supplied to the National Treasury, approximately corresponds to the Government's expenses for the activity in question, in respect of personnel, material and travelling expenses.

Finally, it may be reported that the radiation protection control has been accompanied by a not inconsiderable reduction in the additional premiums for liability insurance which doctors and dentists pay as a rule on the basis of possessing roentgen establishments.

4. Survey of premises and equipment, personnel and scope of work

As appears from what has been said previously, the premises of the Institute have been successively enlarged and improved, both during the time they were located in the buildings of Radiumhemmet in Fjällgatan and also after moving over to the Karolinska sjukhuset. The extent of the premises gives a clear picture of the development of the Institute and of how new fields of activity, research and supervisory work as well as other work projects, have arisen. Figures 3—8 show plans drawn to the same scale for the different stages in the development, from the little partitioned space in the photographic laboratory at Radiumhemmet in 1921, to the present buildings, consisting of the main building, library, radium laboratories, high-voltage laboratory and radon laboratory. The uses of the different premises are shown in the text of the

[1] While changing over from inspection-fees to license-fees.

plans. The picture at the beginning of this issue shows the present appearance of the Institute.

Concerning the equipment it may be mentioned that the laboratory shared one 200 kV roentgen apparatus with the treatment department of Radiumhemmet from 1924—1929. From 1929—1937 it had two 200 KV roentgen apparatuses, one for the standardization laboratory and one for physical and biologic irradiation experiments. During 1938—1947 it had three 200 kV roentgen apparatuses and one 100 kV. Since 1948, in addition, there has been one installation for 1.2 million volts, and one roentgen diffraction apparatus of very great efficiency. Among further equipment, special apparatuses made at the Institute in 1942, for the mounting of radium salt preparations, may be mentioned. A semi-automatic apparatus for the production of radon preparations from a radium solution of one gram of radium, was constructed at the Institute in 1947. (See EGMARK, p. 311 in this issue.) The radon tubes produced are primarily intended for nuclear physics work in university and certain other research laboratories but may also be used for other purposes, *e. g.* special treatments at Radiumhemmet.

The number of the personnel at different times appears from the following table.

Table III

	Personnel with university qualifications	Personnel with lower technical training	Personnel for office, laboratory and calculation work	Personnel in workshops	Total
1921	1				1
1926	1		1		2
1931	5		2		7
1936	5		4		9
1941	6	1	5	1	13
1946	8	2	6	2	18
1950	11	8	11	4	34

The routine work at the Institute has increased extraordinarily, especially during the last years. The measurements for Radiumhemmet of which the majority are performed according to the condenser chamber method, thus show a steady increase, as is apparent from table IV.

The extent of the supervisory activities which, since the taking over of the Institute by the Government and the passing of the Radiation Protection Act in 1941, has increased appreciably, as is made clear by the following table V.

Fig. 3. *Room in Radiumhemmet 1922—1924 for measurements of radium applicators*
(floor area ca. 5 m²).

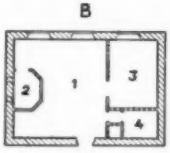
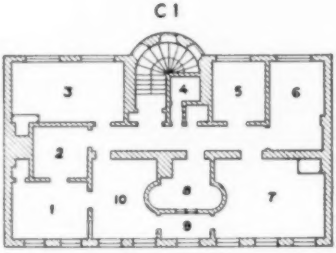


Fig. 4. *The Physical Laboratory of Radiumhemmet 1924—1929*
(floor area ca. 40 m²).
1. Roentgen laboratory.
2. Roentgen tube with protection wall.
3. Writing-room and laboratory for radium measurements.
4. Dark room.



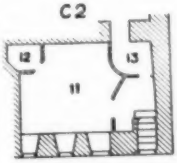


Fig. 5. *The Physical Laboratory of Radiumhemmet 1929—1937*
(floor area ca. 200 m²).
1. Writing-room.
2. Instrument storage.
3. Radium laboratory.
4. Dark room.
5. Workshop.
6. Radium laboratory.
7 and 10. Roentgen laboratories.
8. Roentgen apparatus for two roentgen tubes with protection walls.
9. Control room.
11. Roentgen standardization laboratory.
12. Dark room.
13. Roentgen tube with protection wall.

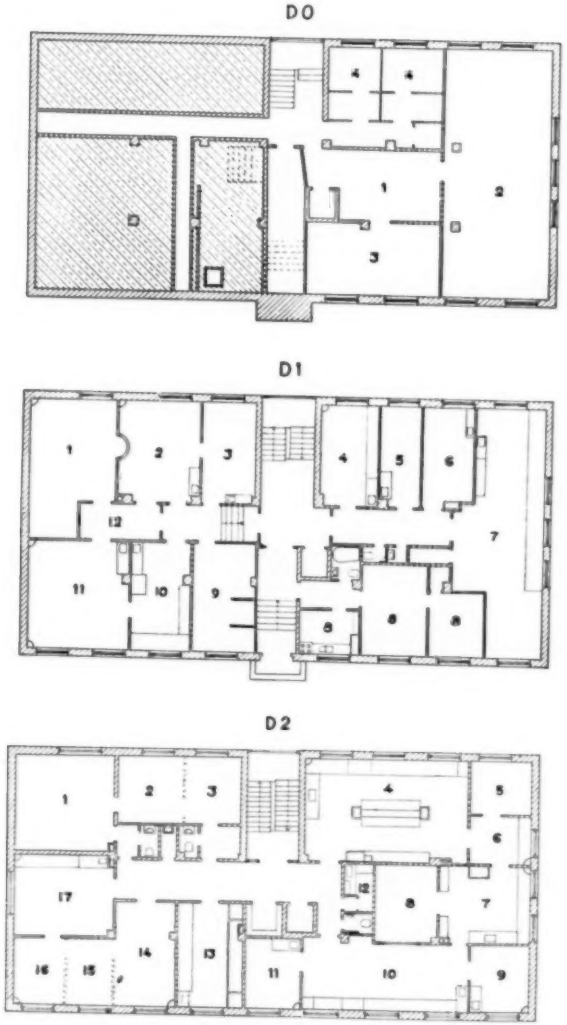

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Fig. 6.

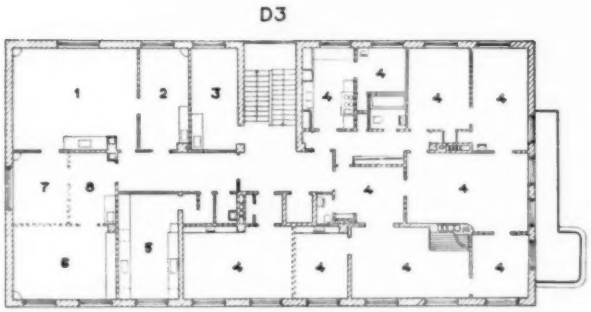

Fig. 6.

Fig. 6. *The Institute of Radiophysics.* Main building erected 1937 (floor area, residences excluded, 850 m²).

D 0. Sub-basement.

1. Workshop and store.
2. Room for biological cultures and for autoclaves, thermostats etc.
3. Store.

D 1. 1st floor.

1. Roentgen ray apparatus (200 kV) and two roentgen tubes for radiation tests in rooms 2 and 11.
2. Roentgen laboratory for absorption measurements.
3. Writing-room for assistant professor (Dept. B).
4. Drawing-office.
5. Workshop for carpentry.
6. Workshop for hardening, soldering and forging.
7. General workshop.
8. Residence for technical assistant.
9. Transformer with voltage regulator and direct current generator.
10. Amplifier workshop.
11. Roentgen standardization laboratory.
12. Control room for roentgen apparatus.

D 2. 1st floor.

1. Writing-room for the Chief of the Institute.
2. Secretary's room.
3. Cashier and registrar room.
4. Biologic and Biochemical laboratory.
5. Writing-room for assistant professor in radiation biology.
6. Balance room.
7. Chemical laboratory.
8. Two roentgen ray apparatuses (200 kV) for roentgen tubes in rooms 9 and 11.
10. Control and general physical measurements room.
12. Dark room.
13. Writing-room for assistant professor (Dept. C).
14. Maps and card-index for supervisory activities.
15—16. Writing-rooms.
17. Writing-room and laboratory for assistant professor (Dept. A).

D 3. 2nd floor.

1—2. Physical laboratory.
3. Laboratory for blood investigations.
4. Residence for the Chief of the Institute.
5. Dark room.
6. Routine laboratory for condenser chamber measurements.
7. Writing-room and laboratory.
8. Storage for reports.

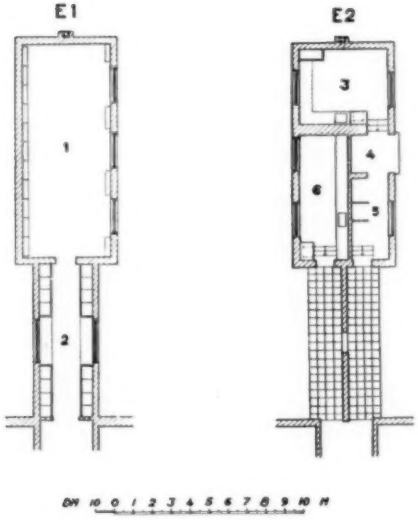

Fig. 7. *Enlargement of the Institute in 1941*
(floor area ca. 100 m²).

1. Library.
2. Communication passage to the main building. Also used for instrument storage.
3. Laboratory for mounting radioactive substances.
4. Loggia.
5. Shower-bath for assistant working with open radioactive preparations.
6. Room for radioactive measurements.

The walls between 3—6 and the flooring between the 1st and 2nd floor give the radiation protection considered necessary.

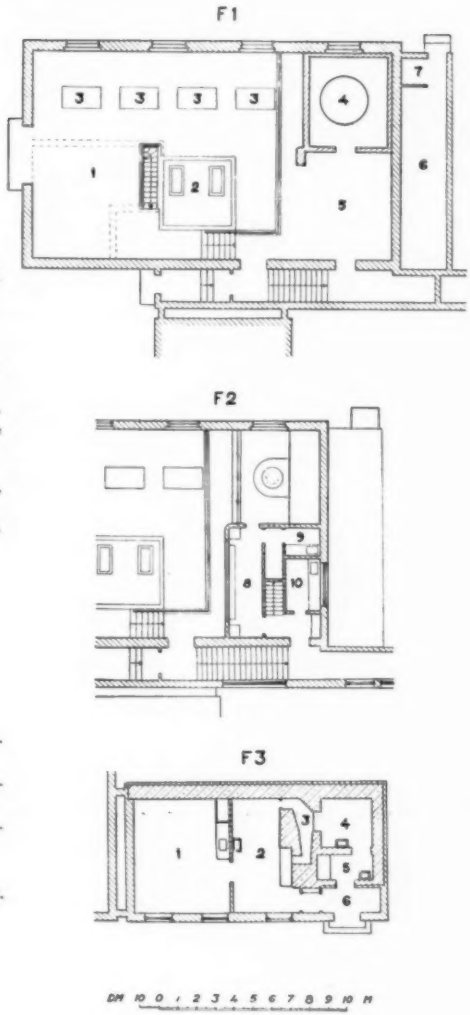

Fig. 8. *Enlargement of the Institute in 1947.*

High voltage laboratory
(floor area ca. 300 m²).

1. Basement room for future investigations with neutron or high voltage roentgen rays.
2. Cascade generator, 1,2 mill. volts.
3. Condenser battery, 40 condensers, 250 kV, 0.11 μF.
4. Laboratory with walls of iron-ore concrete and roentgen tube in the ceiling.
5. Room under control balcony.
6. Accumulator battery, 16 volts, 20,000 amps.
7. Charging set for the accumulator battery.

On the balcony.

8. Control room.
9. Dark room.
10. Room for biological objects.

Radon laboratory
(floor area ca. 70 m²).

1. Laboratory for radioactive measurements.
2. Control room for radon apparatus.
3. Mirror arrangement for observations of radon apparatus.
4. Radon apparatus.
5. Room for radon preparations.
6. Loggia.

Table IV

The increase in the routine work done for Radiumhemmet.
(Measurements according to the condenser chamber method.)

Year	Roentgen and radium radiation measurements on patients. Number of observations	Total number of observations made at the routine laboratory
1932	2,181	16,000
1933	1,222	22,000
1934	1,409	7,700
1935	2,040	9,600
1936	2,750	9,720
1937	3,800	10,500
1938	5,895	16,163
1939	6,253	17,750
1940	8,086	20,670
1941	9,216	23,600
1942	12,210	26,343
1943	12,000	31,616
1944	11,558	26,978
1945	11,875	29,145
1946	13,185	37,989
1947	14,503	34,028
1948	16,868	38,122
1949	12,620[1]	33,592

Table V

The extent of the Institute of Radiophysics' supervisional work.

Dept. A Control of establishments for roentgen diagnostics and establishments for technical, scientific and education purposes;
Dept. B Control of establishments for roentgen treatment;
Dept. C Control of protective measures for radioactive preparations and for testing and mounting of such preparations.

Year	Dept. A		Dept. B		Dept. C	
	Number of establishments	Number of inspections	Number of treatment plants	Number of inspections	Number of establishments	Number of inspections
1939 (pre-inspection fig.)	2,060		79		19	
1941	2,300		89		37	
1942	2,380	1,391	107	297	41	17
1943	2,470		106		43	
1944	2,570	1,613	109	257	46	40
1945	2,670		112		54	
1946	2,780	2,269	113	274	61	49
1947	2,890		121		76	
1948	3,000	1,863[2]	128	305	77	79
1949	3,130		135		88	

[1] Owing to difficulties in obtaining certain replacements, part of the measuring-apparatus has been temporarily out of function.

[2] Owing to the reorganization of the supervision work, the work shows a seeming decrease, despite the increase actually prevailing.

5. Some ideas for the future development of medical radiophysics

In medical radiophysics three projects are strongly interdependent and almost necessary for a well adapted and all-round development, namely *research and teaching, continuous collaboration with a radiotherapeutic clinic* and *radiation protection and dosage control.* These three fields of work have many common needs with respect to premises, equipment and specially educated personnel. Among the most prominent are the following:

Premises and equipment for radiation measurements and for biologic irradiation experiments

1. Laboratories and instruments for calibration in internationally established units of radiation measurement devices of various kinds.
2. Special laboratories for investigation of and work with radioactive substances and radiations of all types.
3. High voltage establishments and particle accelerators.
4. Irradiation devices for large scale biologic experiments.
5. Access to large quantities of radium, radon and other radioactive substances.
6. Well-equipped workshop and designing departments, especially for the construction of special apparatuses for radiation measurements, and apparatus for irradiation of biologic objects.
7. Library for physical and radiologic books and periodicals.

Specially educated personnel

1. *Physicists* with special training within the different fields of medical radiophysics and with understanding of biophysical problems especially in respect to biologic radiation effects, based on extensive collaboration with biologists and medical men.
2. *Biologists* and *biochemists* with knowledge and experience in radiation biology and radiation biochemistry. The biologist and biochemist form a most important link between the physicist and the doctor, as they possess a special capacity for understanding the viewpoints of both these categories.
3. *Medical experts* within the radiation effects field, with special training in haematology and cytology as well as radiology and dermatology.
4. *Designers* and *technically skilled persons* with special training on radiation measurement instruments, high voltage, vacuum, and amplifier technique.

The following should also be pointed out. In order to judge the radiation protection conditions in radiologic work, a knowledge of biological radiation reactions of different kinds is of the greatest importance. Only by co-operation with a radiologic clinic can the physicist gain a sufficiently thorough insight into radiation effects upon the human body, individual variations in skin and blood reactions, the degree of uncertainty prevailing when judging the influence of small radiation doses upon the health, etc. Experience in these fields is indispensable for estimating tolerance and safety doses and for decisions on the selection of suitable dose units. For this latter question, co-operation in biophysical research work is also necessary, both the definition of dose units and the practice of measurements in accepted units being in the first place intended for the needs of medical radiology. The adaptation of measuring techniques to medical and biological demands implies similar problems both in radiation protection supervision and in measurements of therapeutic doses.

From what has been said, it is evident that very strong organizational and economic reasons exist for bringing together in a central institute research and instruction in medical radiophysics, the physicists' routine work in the treatment of patients in a radiotherapeutic clinic and general radiation measurement for protection and dosage control. In this way the resources in premises and equipment could be used to better advantage and experiences from the one field of work could support the work within the other. Such a procedure is accompanied, however, by a disadvantage.

Experience has shown that where routine work and research work are closely associated, as a rule the routine work grows at the expense of the research. During recent years at the Institute of Radiophysics this has made itself strongly felt as the radiation protection control, in reference both to use of the premises and also to occupation of the personnel, has, to a large degree, encroached upon the research work and the physical work for Radiumhemmet. It is especially regrettable that the academically educated supervisory personnel have not been able to carry out research in addition to inspection work, as was anticipated at the beginning. However, it appears that these inconveniences could be removed through a modification of the present organization. If the work of the Institute were distributed to well separated departments and approximately corresponding positions were established in each department, an exchange of personnel could be made from time to time, for example so that supervisory personnel could serve periodically in research and in instruction work or in the physical work for Radiumhemmet. Such an exchange is also to the great advantage of the supervisory operations, as only through contact with radiotherapy and research can the supervisors retain the special competence which is absolutely in-

dispensable to supervisory work. It is also of the greatest importance that hereby supervisory activity as well as research and therapy receive fresh viewpoints and that bureaucracy and humdrum routine is counteracted.

In order to simplify the administrative side of supervision it has been proposed to transfer the right of decision from the Medical Board to the Institute of Radiophysics, and that in this connection the medical staff of the Institute should be increased by the appointment of a whole-time specialist. Further a Council for radiation protection should be established with representatives from the Government Offices and Trade Unions interested in radiological work. This would further the collaboration with those concerned, which is so valuable for the supervisory work of the Institute, and help to bring about a better understanding of, and greater interest in, protection problems. Especially in consideration of the future importance of protection against ionizing radiations within the field of atomic energy, such an arrangement appears to be suitable, as the development in this field is now very rapid and contact between those interested in protection questions gives the best security that appropriate care will be taken when using radiations with new characteristics or under new conditions. The risk of serious injuries, like those that occurred in the early days of roentgenology are here apparent.

The organization which would thus be preferable to the present one of the Institute of Radiophysics, is presented schematically in the accompanying figure 10.

Concerning the premises for an institution of the type which is considered here, certain general rules could be set up. It is a well-known fact that it is difficult entirely to avoid sooner or later having buildings where work with radioactive substances is done contaminated, so that sensitive radiation measurement instruments can no longer be used. Also one radiation investigation often disturbs another. Consequently the construction of several smaller units is preferable to one large building. Thus, administration, library, supervisory activities, conference rooms and possibly also designing office and workshops should be combined in one building, while roentgen investigations, work with sealed and open radioactive preparations and high voltage installations and particle accelerators, as a rule, should be provided with buildings well separated from one another. It is of the greatest value also to have special premises in a milieu as well protected from radiation as possible, as a number of investigations, for example concerning the γ-radiation from the human body and biologic effects of natural radiation, require the most radiation-free laboratories possible. The laboratories, whose walls run the risk of radioactive contamination, must naturally be provided with special ventilating devices and exchangeable wall lining.

RESEARCH COUNCIL OF KING GUSTAF V:s JUBILEE CLINIC
CHIEF OF THE INSTITUTE
ADMINISTRATION
RADIATION PROTECTION COUNCIL
RESEARCH AND INSTRUCTION WORK
WORK FOR "RADIUMHEMMET"
DOSAGE AND PROTECTION SUPERVISION
1
2
MEDICAL RADIATION PHYSICS, BIOPHYSICS
RADIATION BIOLOGY, BIOCHEMISTRY
LIBRARY, DOCUMENTATION
HOSPITAL PHYSICS
MEDICAL SPECIALIST: RESEARCH AND CONTROL
CONTROL DEPT A: ROENTGEN RAYS IN DIAGNOSTICS, INDUSTRY, RESEARCH, AND TEACHING
CONTROL DEPT B: ROENTGEN RAY THERAPY
CONTROL DEPT C: STORAGE AND USE OF RADIOACTIVE SUBSTANCES
PRODUCTION OF RADIOACTIVE PREPARATIONS
IRRADIATION OF PHYSICAL AND BIOLOGICAL OBJECTS
RADIATION MEASUREMENTS AND INSTRUMENT TESTING
DESIGNING OF INSTRUMENTS
WORKSHOP FOR MECHANICAL AND AMPLIFIER WORK
LABORATORY FOR BLOOD INVESTIGATIONS
SUBORDINATION
COLLABORATION

Fig. 9.

From time to time there is to be an exchange of personnel with university qualifications between 1 and 2.

The points which are brought out in this article, must, in the author's opinion, of necessity be considered in the organization of the work in medical radiophysics. Concerning a number of details, experience from the countries in which atomic energy research occupies an advanced position may give rise to further and perhaps partly differing views. On the whole, however, the principles maintained here will in all circumstances have a universal application. The control of radiation protection and radiation dosage demands knowledge of and co-operation with radiation biology and radiotherapy. For the application of physics in radiotherapy, co-operation with those who work in the fields of radiation protection and dosage control and use of their experience is absolutely necessary, and scientific research in the abovementioned fields deals on the whole with the same problems which are of fundamental importance to the practical work.

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SUMMARY

On account of the increased interest that during the last few years has been shown in medical radiophysics, the author, after a general historical outline of the development of radiophysics in Sweden, gives information regarding its present organization in this country. As the supervision in Sweden of radiological work, on which an Act was passed in 1941, seems to have proved of interest to foreign countries, the author feels called upon to give the text to all more important laws and regulations at present valid in Sweden within this domain, and also to give a short account of the circumstances leading up to them and the activities they have given rise to.

After a short survey of the development of the Institute of Radiophysics as regards premises, equipment, and personnel, the author gives some views on the need for a further development of the organization of the Institute, and emphasizes the importance of radiation-protection and dose-control being coordinated with research in medical radiophysics and located at centrally situated institutes giving the opportunity of daily cooperation with a large radiotherapeutic clinic.

The article closes with an index of literature published by Swedish institutes for medical radiophysics.

ZUSAMMENFASSUNG

Aus Anlass des gesteigerten Interesses, welches in den letzten Jahren der medizinischen Radiophysik entgegengebracht wird, gibt der Verfasser, nach einem geschichtlichen Überblick über die Entwicklung dieses Gebietes in Schweden, Angaben über die jetzige Organisation. Da besonders die Besichtigung radiologischer Arbeit gemäss eines 1941 erlassenen Gesetzes das Ausland interessiert hat, teilt der Verfasser den Text aller wichtigeren in Schweden auf diesem Gebiete geltenden Gesetze und Verordnungen mit und gibt ausserdem eine kurze Darstellung des Zustandekommens derselben und der daraus veranlassten Tätigkeit.

Nach einem Überblick über die Entwicklung des Radiophysikalischen Institutes mit Hinsicht auf Lokale, Ausrüstung und Personal gibt der Verfasser einige Gesichtspunkte über die Notwendigkeit eines weiteren Ausbaues der Organisation des Institutes und betont die Wichtigkeit, dass Strahlenschutz- und Dosierungskontrolle sowie Forschung in der medizinischen Radiophysik Hand in Hand gehen und in ein zentrales Institut, mit Möglichkeit täglicher Zusammenarbeit mit einer grösseren radiotherapeutischen Klinik, verlegt werden.

Den Artikel beschliesst ein Literaturverzeichnis über Veröffentlichungen schwedischer Institute für medizinische Radiophysik.

RÉSUMÉ

Vu l'intérêt croissant que la Radiophysique médicale a soulevé ces dernières années, après une revue historique générale de son développement en Suède, on apporte des données sur son organisation actuelle dans ce pays. Attendu que c'est surtout la réglementation du travail radiologique d'après une loi promulguée en 1941 qui a attiré l'attention de l'étranger, l'auteur a cru devoir communiquer le texte de toutes les principales lois et ordonnances en vigueur dans ce domaine en Suède, et indiquer brièvement leur origine ainsi que l'activité qui en est résultée.

L'auteur décrit le développement de l'Institut de Radiophysique en ce qui concerne les locaux, l'outillage et le personnel, puis émet certains jugements touchant le besoin d'une nouvelle extension de cette organisation; il souligne combien il est important de coordonner le contrôle des mesures de protection contre les rayons et des méthodes de dosage avec les recherches dans le champ de la radiophysique médicale dans un Institut central où l'on pourra collaborer journellement avec une grande clinique radiothérapique.

L'article se termine par une revue bibliographique des publications des Instituts suédois specialisés en radiophysique médicale.

FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

FEATURES OF THE SYSTEM OF PERIODICAL INSPECTION ADOPTED FOR ROENTGEN THERAPY INSTALLATIONS IN SWEDEN, AND SOME EXPERIENCES OF THE INSPECTION WORK[1]

by

R. Thoræus

During the period 1895—1920 medical radiology grew from a narrow speciality to a scientific branch of medicine, incorporated into the general medical routine. The proper use of roentgen rays was, however, soon found to require a thorough knowledge of their physical properties, and the need of such knowledge was particularly pronounced in the rapidly growing radiotherapy. Hence, when the Radiumhemmet radiophysical laboratory was established in 1921 experience had already demonstrated the great practical and clinical necessity of intimate cooperation between radiologists and physicists.

From the very beginning the research work in this laboratory was devoted to various physical problems of dosage, and great efforts were made to substitute physical measuring methods for the previously used empirical methods. In doing this it was, however, found necessary to investigate by the new methods the dosage conditions in use (3). In that way it was considered possible to put the clinical work on a more solid basis, to introduce physical standards, and to maintain the desired uniformity in both dosage and operating conditions.

The introduction of this physical inspection of the roentgen therapy installations at Radiumhemmet was very soon found to be of a great practical value to the clinic. Hence, in 1925, SIEVERT offered to extend that work to include inspection twice a year of all the therapy departments in Sweden. This was immediately accepted, and a separate department of roentgen therapy inspection was accordingly established (2) at the end of 1925. This department of the laboratory has since been work-

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ing to full capacity, and without interruption. Since the beginning of 1927 it has been in the charge of the author.

During its first 15 years the radiophysics laboratory was frequently consulted on questions of protection. In 1941, however, a law was passed placing all radiological work in this country under the supervision of the Royal Board of Medicine, and the radiophysics laboratory was commissioned to inspect periodically the protective measures taken. As far as the roentgen therapy installations were concerned, it was found quite natural to combine the inspection of the protection with the already existing physical inspection of dosage. In 1941 the department of roentgen therapy inspection was, therefore, re-organized accordingly, and has since been following the program briefly outlined below.

All roentgen therapy departments are visited and inspected twice a year. At each inspection the operating conditions and the physical factors influencing the dosage are investigated by direct measurement observations. At the first inspection of an installation the permanent arrangements for protection are thoroughly examined, and this is repeated once more at the second inspection, usually by another inspector. If details of the protection need to be supplemented or adjusted, or if adequate protection cannot be obtained by permanent arrangements, advice is given as to suitable means for their improvement, or any additional protection required. At the subsequent inspections the results are checked.

It may be mentioned here that the system of periodical inspection was not made compulsory until 1941. Nevertheless all the therapy departments applied to the laboratory for such inspection. This seems to verify the practical value of the system.

Statistical Details

At the end of 1926 the total number of therapy installations (treatment units) inspected was 19. Since then the number has increased very much and is at present 137, or more than seven times larger, as illustrated in fig. 1. The period 1926—1932 is characterized by the so far most rapid progress of roentgen therapy in Sweden. In this period of six years the number of therapy departments increased from 10 to 45, *i. e.* by an average of nearly six each year. In 1933 two private departments were closed down, and since then all are hospital departments. In the period 1928—1936 one Norwegian hospital therapy department was by special request included in our periodical inspections. However, in 1937 a similar inspection was started in Norway.

Of the present installations 115 are of the 200 kV type, the remaining 22 being of the short focal distance type. All departments except one have 200 kV installations, 67 per cent of them, however, only one.

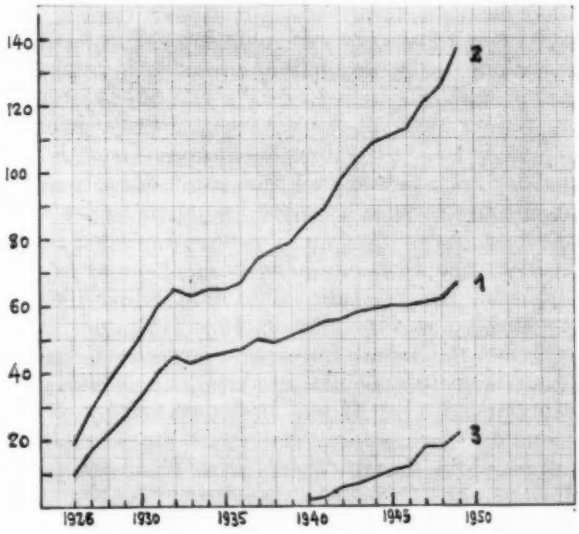

Fig. 1.
1 = number of therapy departments
2 = total number of installations
3 = number of short focal distance installations.

This is the actual reason for our general requirement that a 200 kV installation must be constructed to allow both superficial and deep therapy. This implies that the filtration inherent in the roentgen tube and its protective enclosure is sufficiently small, and that tube-voltages from about 80 up to 200 kV are available. Practical limits of the inherent filtration are further discussed later.

Comparing the curves in fig. 1, it will be seen that since 1936 the number of installations has increased proportionally more rapidly than the number of departments. This shows how the departments themselves have developed. Since 1940 that development has been partly due to short focal distance installations, the use of which may be considered supplementary to that of a 200 kV installation, and allows a higher degree of individualization of the treatment. Such improvements and developments of the therapy equipment will, however, also increase the demand for more highly qualified and experienced radiologists as a sine qua non for the competent use of the equipment in the clinical work.

The diagram also clearly shows that the number of both departments and installations is still increasing. At present a number of installations are ordered. One of them, a 400 kV unit ordered by the Radiumhemmet, is the first in this country permitting clinical therapy at tube-voltages above 200 kV. That installation will probably require a great deal of preparatory measurements and other studies before any treatment is begun. Within the next few years the rotation technique may be expected

to come into more wide-spread use; besides that, a number of therapy units using the very soft radiation called "grenz-rays" are expected to be installed. In the next quinquennial period the total number of installations will probably be increased by about 30, as far as can be assessed at present.

Before 1930 all the roentgen therapy installations were incompletely shielded by protective enclosure. The high-voltage conductors were usually uncovered, and the commonest roentgen ray absorbing shield at the tube was a more or less open lead-glass bowl. In 1929, however, the first high-voltage cables were installed in Sweden (Radiumhemmet), in 1932 the first completely shock-proof and ray-proof enclosure of a 200 kV therapy tube. The first completely protected Swedish-made installation was installed in 1934 (14), and has ever since been operating without technical failures or accidents. Subsequently, the percentage of such enclosures has gradually increased. That increase became more pronounced when it had been verified by experience that the operating economy of the tube, that is its life in relation to its price, was much improved in therapy tubes with complete protective enclosure (12). To illustrate this, it may be mentioned that the percentage of such enclosures in 200 kV installations was 5 per cent at the end of 1934, 24 per cent at the end of 1936, 58 per cent at the end of 1938 and 71 per cent at the end of 1940. At present there are only five installations lacking this type of modern protective equipment. Two of them have ordered such equipment, and will accordingly be modernized in about a year. Of the present number of protective enclosures in 200 kV installations about 70 per cent are Swedish-made.

The Periodical Dosage Control

The tube-voltage and the tube-current are undoubtedly the most important operating conditions of a roentgen therapy installation. They are therefore directly measured with the aid of a portable sphere-gap of standard shape and size (5) and a carefully calibrated high-voltage mA-meter. The accuracy and reliable functioning of the stationary instruments used for the direct or indirect reading of these operating conditions are tested at the same time.

Ordinary 200 kV therapy tubes are not operated at more than about 170 kV. The reason for this is the relatively high cost of the tubes and the consequent demand for a reasonable average tube life. At the maximum tube-voltage and milliamperage, the life guaranteed by the manufacturer is usually about 300 hours of operation. On the basis of our experience of many years, we have arrived at the following standard tube-voltages of constant potential, 1 Al: 100—105 kV, 4 Al: 140—145 kV, and 0.5 Cu- or Tin-filter: maximum about 170 kV. Using these

standard values, we actually get an average tube life of more than 1,000 hours, and in some cases many thousand hours have been recorded. The said standard combinations correspond to the following half-value-layers: 1 Al: HVL = 0.1 mm Cu, 4 Al: 0.3 mm Cu, 0.5 Cu: 0.8 mm Cu, and Tin-filter: 1.6 mm Cu. The question of filtration and its economy has been repeatedly studied by both calculations (13) and experiments (5, 7, 8, 12, 18), and the above standards are the results of this.

The tin-filter described by the author at the Second International Congress of Radiology in 1928 was the first compound filter ever used in roentgen therapy to consist of more than two components and to use elements of higher atomic numbers than copper. Its main component was tin, and the principle of successive backing was introduced for the arrangement and dimensioning of its other components. Such filters were found to be superior in filtration economy, and are now widely used in many kinds of high-voltage roentgen therapy.

The tube-current is mainly selected to satisfy the actual need of dose-rate, but the maximum rating must not be exceeded. For most combinations of filter and tube-voltage, two mA-values are available, one corresponding to a surface dose-rate of about 35—45 r per minute, the other to one of 80—100 r per minute, both referring to a focal distance of 40 cm and a field size of 10 × 10 cm. The lower dose-rates are mainly used for the application of small doses, and the higher for large doses (usually above 200 r).

The use of a therapy tube in both superficial and deep therapy requires that the inherent filtration, Fi, of the tube and its protective enclosure is sufficiently low. Fi-values equivalent to 1—1.5 mm Al are considered normal. In cases of higher Fi-values the thickness of the additional filters 1 Al and 4 Al are accordingly reduced. Tubes of Fi-values above 2.5 mm Al are considered unsuitable and thus usually not accepted. This condition is connected with the fact, that most roentgen departments have only one therapy installation to be used for both superficial and deep therapy. Fi is checked by measuring the absorption in aluminium by a simple method developed by the author on the basis of previously published experimental results (18).

The above tube-voltages refer to constant potential generators. This type of high-voltage generator is extensively used in Sweden because of its high efficiency and well-defined operating conditions. Of the present number of 200 kV installations 88 per cent are of the constant potential type.

The laboratory's first instrument for roentgen ray measurements was designed by SIEVERT (1), constructed in the laboratory, and subsequently in 1924 and 1929, calibrated for dose-rate measurements free in air at the Physikalisch-Technische Reichsanstalt of Berlin. This

instrument was solely intended for dose-rate measurements free in air, and was thus adapted to the general requirements actual before 1930. However, later there appeared a clinical demand for the consistent introduction of the effective dose (backscatter included). Since the said instrument was provided with a very large ionisation chamber, it could not be used for the direct measurement of effective doses, for instance within or at the surface of a phantom, using ordinary field sizes. The calibrations had also shown that the chamber was not as independent of wave-length as was desired (5), and, hence, that reliable measuring results free in air could not be obtained by that instrument unless the quality of the radiation was at least approximately known. In the beginning of the nineteen-thirties a standard open air ionisation chamber in accordance with the definition of the r-unit was, therefore, designed and constructed by the author (5). With this instrument accurate measurements, and calibrations of other chambers, both in terms of the r-unit, could be made in the laboratory. The standard chamber was provided with a complete 200 kV constant potential installation. An improved modification of the open air standard chamber was later designed (22).

On account of its principle and dimensions, a standard open air chamber cannot be used for measuring effective doses or dose-rates. When the first open air standard chamber had been completed, it was therefore necessary to construct an instrument for use as secondary standard. For this purpose a specially adapted variant of the condenser chamber principle, introduced by SIEVERT in 1926, was designed by the author. Using graphite ionisation chambers, and interchangeable additional capacitors it was found rather easy to construct secondary standards of extensive wave-length independence (11). It was even found possible, by using a simple design and easily accessible materials, to construct a small closed chamber able to serve as a portable substitute for the standard chamber (19). Graphite condenser chambers of high sensitivity — and accordingly suitable for measuring protection — have also been constructed (15). In this work sensitivities up to 2.5×10^{-5} r per volt have later been attained without difficulty. The design and constructional features of a sensitive and wavelength-independent condenser chamber of this kind will be described in another paper.

Early in the nineteen-forties roentgen therapy installations of very short focal distances (15—18 mm), high dose-rates (up to 14,000 r per minute), and initial filtrations as low as 0.2 mm Al, were introduced in Sweden. In these installations the ordinary graphite chamber cannot be used for measuring doses and dose-rates, since the soft radiation emitted is to a considerable extent absorbed in the wall of the chamber, the size of which is moreover too large in relation to the short focal distance used. A very thin-walled chamber of small dimensions was therefore

designed and constructed by the author. A description of that instrument will be communicated later.

As may be understood, the problem of measuring the effective doses and dose-rates sufficiently accurately in roentgen therapy is very extensive, and because of its fundamental clinical importance it needs continuous attention. The recently developed types of therapy tube with a vacuum-tight beryllium window in the tube wall for the exit of the radiation will, for instance, probably require extensive study to ascertain the effect of the increased amount of very soft radiation transmitted by such windows, and of the extremely high dose-rates that may be obtained from these tubes.

When inspecting ordinary 200 kV therapy installations, the dose-rates corresponding to the actual or desired combinations of additional filter, tube-voltage, and tube-current, are measured by means of the abovementioned secondary standard at the surface of a wax-phantom, 40 cm from the focus, using a 10×10 cm field. Tables to correlate the dose with the treatment time at various focal distances are prepared from the results and left at the switch-table, together with standard tables from which the corrected treatment times corresponding to any other field sizes than 10×10 are directly obtained.

It may be mentioned here that a change-over to a general use of efficient doses and dose-rates, both in terms of the r-unit, was effected in 1935. To facilitate that change, tables showing the correlation of the two dosage systems were compiled from measurements taken by the author (9), and sent out to all the roentgen therapy departments.

In the short focal distance therapy installations the dose-rates at the phantom surface are measured with the various applicators and filters in treatment position. A direct result is then obtained, from which tables of the treatment times corresponding to desired effective doses are made out and issued to the installations.

From measurements in this laboratory (5, 8), and from results communicated by other laboratories, depth-dose tables for 200 kV installations were compiled at an early date, copies of which were sent to all the departments. Particulars of actual results of investigations in our laboratory or published by other laboratories are usually, as far as they are considered applicable to our treatment conditions, communicated to the therapy departments, when these are inspected.

Routine Control of the Dose-Rate Constancy

It should be remembered that the original system of periodical inspection of 200 kV installations was planned and introduced at an early stage of roentgen therapy, when no reliable dose-meters were available

Fig. 2. Reading instrument of the control intensimeter.

in the market. The therapy installations in use at that time were not as technically perfect as those in use to-day; the inconstancy of the dose-rates was a source of much trouble, and it was very difficult to maintain the required accuracy of the dosage. It was, however, clearly understood that this system of periodical inspection could form the basis of a convenient dosage system only if the dose-rates could be kept fairly constant. Hence, some kind of an easily handled instrument of simple design and reliable function was essential for checking the operation constancy of the installation by measuring the primary dose-rate. Such an instrument was first designed by SIEVERT (2), constructed in the laboratory, and was called a »control-intensimeter». Since that instrument is considered an integral part of the system, it is supplied by the laboratory at the first inspection, and at a price corresponding to the laboratory's own expenses only.

In its present construction, improved by the author and Mr. P. HAGLUND, this instrument consists of a small galvanometer, connected to a large aluminium ionisation chamber by means of an electrically shielded and rubber insulated cable. In the lower part of the wooden galvanometer housing, fig. 2, a special space is provided for the electrical equipment needed to maintain a difference in potential of about 200 volts between the electrodes of the chamber, and to feed the galvanometer lamp. Saturation current in the ionisation chamber is obtained at about 70 volt. Since this instrument is not intended for real dose-rate measurements in terms of the r-unit, an extensive wave-length independence of the ionisation chamber is neither required nor particularly aimed at.

When the instrument is to be used, the chamber is placed on the floor, and the roentgen tube adjusted to a certain focal distance above the chamber, which at the first inspection is empirically determined to get suitable deflections in relation to the dose-rates; in most cases these

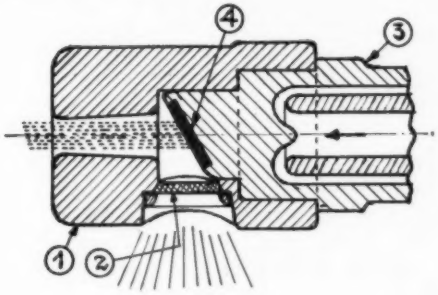

Fig. 3 a. Hooded anode of a 200 kV—6 mA therapy tube.
1 = copper hood.
2 = beryllium window.
3 = anode copper stem.
4 = tungsten button.

Fig. 3 b. Radiograph of the anode head in a 200 kV—6 mA tube, showing peeled tungsten button.

Fig. 3 c. Radiograph of the anode head in a 200 kV—15 mA tube, showing peeled tungsten button.

are obtained at 60—80 cm. The tube is then operated, and the deflection of the galvanometer light spot read. In this manner it is easy to check the constancy of the dose-rates corresponding to the combinations of operating conditions used. Such checking is usually done every other day, or at least twice a week. Many years of experience have clearly demonstrated the great practical value of this relatively simple instrument.

It may, for example, be mentioned here that the very treacherous source of error — that the tungsten button peels from the copper body of the roentgen tube anode — was first noticed as considerably reduced readings on the control intensimeter, while no other signs of disturbed operation could be observed (17, 21). Even a tube in which the tungsten button had peeled so much that the radiation exit opening in the copper hood of the anode was entirely covered, might operate perfectly well, but the dose-rate was found to be reduced to a few per cent of its initial value. Therapy tubes with an evident tendency to continuously reduced dose-rates should be radiographed. In our laboratory we do that by

exposing the photographic film to a small 50 mg radium container for about 16 hours at a distance of 1.2 meter, stationing the roentgen tube just in front of the film casette. A diagram showing in principle construction of the hooded anode, and two radiographs obtained in this way, are shown in fig. 3. The completely peeled tungsten button is clearly seen.

Further Details, and some Experiences of the Dosage Control

It is, however, not only the operating conditions and the physical basis of the dosage that are periodically inspected. The function and accuracy of practically all accessory equipment, such as filters, focal distance indicators, cone-applicators, hole-diaphragms, shutters and timers, are also tested. Some of these details are further discussed in connection with the protection.

The reason for all these tests is the general demand that the therapy installations should be kept at the highest possible level of reliability and accuracy. If there is reason to assume, from reports received by telephone or letter, that an installation is not in due order, an extra inspection is accordingly made as soon as possible. The records obtained by means of the control-intensimeter have proved to be of a very great value in such cases, and also when old roentgen or valve tubes have to be replaced.

Some installations have a spare roentgen tube. This is operated at an inspection, and a complete set of measurements taken. As a rule the tube may then be inserted and used whenever wanted without any extra inspection.

At the first inspection every new 200 kV installation is subjected to a special test, including continuous operation for two hours at the highest operating conditions used in practice (usually about 170 kV and 15 mA). Experience has shown that if an installation has passed such a test without any technical failure, a pretty safe and reliable performance may normally be expected for the immediate future. This test usually leaves sufficient time to examine the permanent protective arrangements.

Practically all the 200 kV therapy tubes at present used in protective enclosure are oil-cooled. After preliminary experiments by the author, this system was as early as 1929 introduced in the Radiumhemmet roentgen therapy department (5, 14, 16), and has since then in practice demonstrated its efficacy and convenience, provided oils of the proper quality are used and the oil-flow is adequate.

In my opinion, based on experience, the therapy installations have now attained a high state of technical perfection and reliability. It should be noted, however, that this experience mainly refers to con-

stant potential generators and air-filled tube-containers. We have no experience of oil-immersed therapy tubes; they are actually not required in our climate. To the average therapy department in this country, oil-immersed tubes may be considered an undesirable complication. The constant potential generator with its well-defined operating conditions, combined with an air-filled protective enclosure that can easily be opened for inspection, for direct measurements of tube-voltage and milliamperage, or for easy replacement of an old tube, and — last but not least — allowing the alternative use of oil-cooled therapy tubes of various makes, has undoubtedly proved to be the ideal and safest type of 200 kV installation under both peace and war-time conditions. Another advantage is that tubes of different makes may under normal circumstances be obtained on trial and the one proving to be the best be selected. New types of tubes may also readily be tried. The enclosures are by no means of inconvenient size, and are generally preferable in countries where therapy tubes are not manufactured. Only in installations planned for particular purposes requiring the smallest possible size and weight may it be necessary to accept an oil-immersed tube as a complement to the normal equipment.

One advantage of these periodical inspections, the practical value of which has been clearly demonstrated, is the central collection of all kinds of experience. As the operating conditions are standardized the results obtained from the various therapy departments relating to, for instance, the life of therapy- and valve-tubes, are comparable, which makes possible to get some idea of reasonable average values within a relatively short time.

A convenient detail of the modern 200 kV therapy equipment is the electrical timer, which automatically closes the shutter at the end of the pre-determined treatment time. These timers must, however, be fitted with a clearly visible motion control. The maximum time to which the timer can be set should be 30 minutes if no more than 8 mA is used, and 15 minutes if 15 or 20 mA is used. The latter type may, of course, also be used at the lower milliamperages, and the 200 kV installations are therefore normally provided with 15-minute timers, in which each scale division corresponds to one tenth of a minute.

The accuracy of the timers is checked by a stop-watch at the inspection. Readings are then normally taken at 2, 5 and 10 minutes. Treatment times below two minutes should as far as possible be avoided in clinical work. If such short times must be used, however, they ought to be checked by stop-watch, and the operating conditions of the tube should be very carefully controlled. In short focal distance therapy the dose-rates used are considerably higher, and the maximum pre-determined time accordingly smaller. Particularly in the Philips unit, the treat-

ment times are usually far less than one minute, and a timer with an automatic cut-out and of a corresponding accuracy is therefore essential.

In the author's opinion the use of very high dose-rates should not be allowed unless the therapy unit is provided with a sufficiently accurate timer with automatic cut-out, and with arrangements to ensure reliable and constant operation. At dose-rates of an order of magnitude of, say, 10,000 r per minute, the exposure times corresponding to the most frequently used doses amount to only a few seconds, and the requisite time to keep tube-voltage and tube-current at their proper values is then not available. These very important operating factors must therefore be kept reasonably constant by an automatic and effective stabilization of the circuits. Such high dose-rates are usually associated with the use of very small focal distances. The applicators, filters used, and other details required for the adjustment of tube position and treatment fields, must accordingly be designed to allow a corresponding accuracy. To maintain the same accuracy in dosage, the demands for a perfect design are considerably higher in high than in low dose-rate units.

Some therapy departments have commercial dose-meters of their own. If such an instrument is functioning properly, it is usually calibrated against our secondary standard at the inspection. But that calibration is only a comparison of the doses or dose-rates at the radiation qualities used in therapy by that particular installation. This simplified calibration takes some 2—4 hours. During the past years inconstant, and thus unreliable, dose-meters have been found. However, the laboratory does not undertake repairs or extensive adjustments of dose-meters, nor does it accept responsibility for their constancy or accuracy.

General Basis of the Inspection of Protection

Protection in radiological work was formerly based on the so-called Mutscheller tolerance dose of 0.25 r per working-day. It has long been felt, however, that such a daily dose is too high for a total irradiation of the human body, when the penetrating power of the radiation is similar to that used in ordinary roentgen therapy and diagnostics.

In the last edition of the detailed German rules of roentgen ray protection, dated May 1943, the following values are given for the maximum permissible daily dose (measured in air) in ordinary therapy work: 1) 0.025 r in places where all kinds of full time workers have to remain (switch-table room, etc.), and 2) 0.25 r in places that are only occasionally occupied by people (corridors etc.). The reason for this recommendation of a daily dose of only one tenth of the Mutscheller tolerance dose for all full time workers remaining in the vicinity of an ordinary therapy instal-

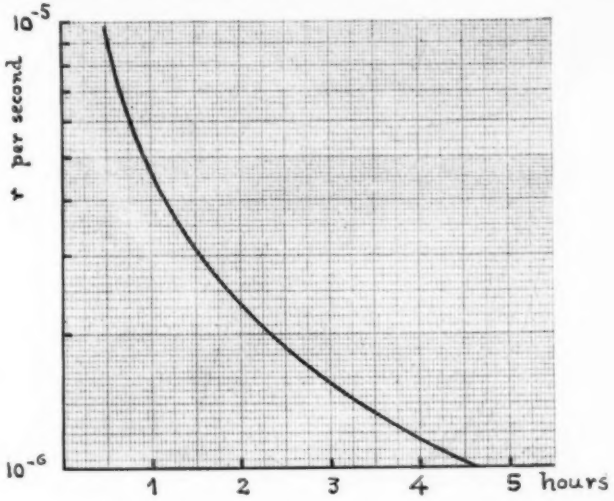

Fig. 4.

lation, is the great sensitivity to roentgen rays of the blood-forming and the generative organs.

However, for lack of a definite answer to the question of the maximum permissible daily dose in roentgen therapy, or of an international agreement on this point, and yet in immediate need of a value to be used as a basis for the inspection of protection in ordinary 200 kV therapy installations, a value of 0.1 r per week, or about 0.02 r per day has been provisionally used as reasonable. On that basis, the maximum permissible dose-rate in r per second corresponding to various numbers of hours of operation per day can easily be calculated. This may be seen from the semi-logarithmic diagram in fig. 4.

As mentioned before, ordinary 200 kV therapy installations are not operated at more than about 170 kV. In practically all the Swedish roentgen therapy departments the protection in walls, floorings, and ceilings has long been planned on the basis of 4 mm of lead. The efficacy of that protection may be found from the recommendations in the above-mentioned last edition of the German rules of roentgen ray protection. At a maximum tube-voltage of 175 kV, and a focal distance of 2 m, the dose-rate is 0.01 r per hour, or about 3×10^{-6} r per second, behind walls of the following lead equivalents:

tube current mA	5	10	20	30
lead equivalent mm	3.2	3.5	3.9	4.1

The above figures allow 2.5 hours of operation per day without exceeding a day-dose of 0.025 r. From the lead equivalents it will be seen that,

according to these rules, 4 mm of lead will allow a tube current of about 25 mA. This is more than the 20 mA at present available.

Measurements in this laboratory have shown that the transmission in 4 mm lead is 7.5×10^{-6} when the irradiated field is large, the tube-voltage 170 kV constant potential, and the inherent filtration of the tube about 1 mm aluminium. The primary dose-rate in air at the same voltage and at a focal distance of 2 metre was 0.77 r per minute per mA. Under these conditions, and using a tube-current of 20 mA, we get a dose-rate behind 4 mm of lead of $20 \times 0.77 \times 7.5 \times 10^{-6} = 1.1 \times 10^{-4}$ r per minute. Assuming a daily dose of one sixth of 0.1 r, the maximum permissible average time of operation per day is about 150 minutes, or an exposure of $150 \times 20 = 3{,}000$ mA-minutes. This value refers to a tube-voltage of about 170 kV, which is used with the copper- and tin-filters.

The aluminium filters are used with considerably lower tube-voltages (100—140 kV), and each mA-minute of operation with such filters will accordingly contribute less to the radiation transmitted by 4 mm lead than that transmitted at 170 kV. The above measurements further show that the transmission and primary dose-rate at 140 kV were respectively 0.32 and 0.78, and at 100 kV 0.16 and 0.49, of those at 170 kV. The number of mA-minutes at 140 kV should thus be multiplied with $k_1 = 0.32 \times \times 0.78 = 0.25$ and at 100 kV with $k_1 = 0.16 \times 0.49 = 0.08$, and then added to the number of mA-minutes at 170 kV ($k_1 = 1.0$) to get the total effect of the operation.

In the diagram in fig. 5 the values of k_1 are plotted against the tube-voltages. If mAm signifies the number of mA-minutes per day at each particular tube-voltage used, and k_1 the factor of efficacy at that tube-voltage obtained from fig. 5, we may put the daily total at $\Sigma(k_1 \times \mathrm{mAm})$. This may be permitted to amount to an average of 3,000 maximum at a focal distance of 2 metre, or $3{,}000 \times \left(\frac{d}{2}\right)^2$ if the focal distance is d metre. As a rule, the contribution of all the mA-minutes is referred to the same point (total effect), and the following formula should accordingly be used:

$$\Sigma(k_1 \times \mathrm{mAm}) \leqq 3{,}000 \times \left(\frac{d}{2}\right)^2.$$

In most treatments of the usual types the beam is directed more or less vertically downwards, and will thus seldom strike the protective walls of the treatment room. With a protection of 4 mm lead in the walls, there is undoubtedly a considerable degree of safety in horizontal directions, whereas the protective power of the flooring under the same conditions probably is almost fully utilized if the total of mA-minutes, calculated by the above formula, averages 3,000 per day.

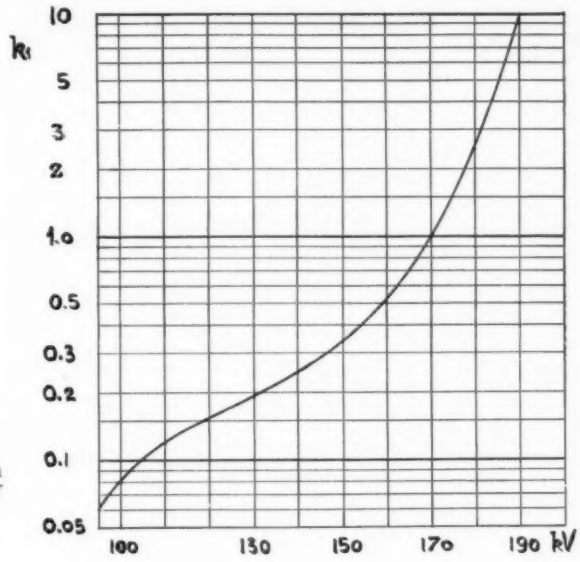

Fig. 5. Variation of k_1 with tube-voltage in kV const. potential.

From the diagram in fig. 5 it is, however, also seen that k_1 is increasing very rapidly with tube-voltages exceeding 170 kV. At 190 kV, for example, $k_1 = 10$, which reduces the maximum number of mA-minutes to 300 if that tube-voltage alone is used.

A similar differentiation may be made in each branch of radiological work in which pre-determined quantities of well defined radiation qualities are administered. As a rule this condition is fulfilled in all kinds of roentgen therapy.

In addition it may be pointed out that the amount of secondary radiation emitted by a patient in deep therapy is considerable. From actual measurements in the Radiumhemmet it was found that 2×10^{-3} of a treatment dose is obtained at a distance of one metre from the centre of a 250 cm² field. Using the 0.5 Cu filter, 170 kV and 15 mA, and 40 cm focal distance, the dose-rate at the skin may be about 90 r per minute when fields of moderate size are used. Hence the secondary radiation dose-rate will be $90 \times 2 \times 10^{-3}$, or about 0.2 r per minute at a distance of one metre from the field. This means that an unprotected person at this distance will receive the maximum daily dose (0.02 r) when exposed for about 6 seconds, or for about 25 seconds at a distance of two metres.

In short focal distance therapy the Philips treatment unit requires particular attention. As a rule the workers are staying in the treatment room in immediate vicinity of the treatment field, and are thus more or

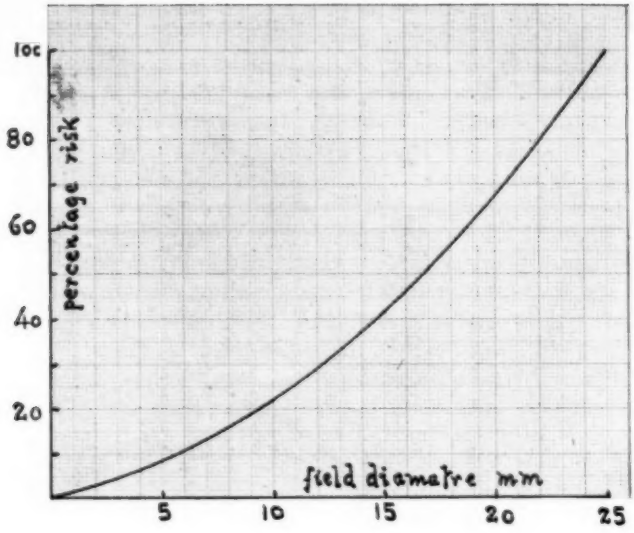

Fig. 6.

less exposed to the secondary radiation from the tissue irradiated. Using the maximum field size (25 mm in diameter), the smallest available focal distance (18 mm), and no additional filter, the maximum amount of secondary radiation (measured in air) to which the workers would be exposed at a distance of 35 cm from the field is about 3×10^{-5} of the treatment dose. That risk is reduced if smaller fields are used. This is illustrated by the diagram in fig. 6 in which the percentage risk is plotted against the field diameter. The values are quoted from a technical description of this treatment unit, issued by PHILIPS in 1942. Since this kind of treatment is associated with such risks, special provision must be made for the protection of the workers. These are discussed later.

It should be noted, however, that the radiation in this type of installation is very soft, the half-value-layer being of the order of magnitude of 0.5 mm aluminium, whereas in ordinary roentgen therapy the half-value-layer of the radiation is 0.1 to 2 mm copper. Generally speaking, it would therefore seem necessary to consider the penetrating power of the radiation in discussing the maximum weekly dose to which full-time workers employed in radiological work may be exposed without danger. It is certainly not easy to find a suitably balanced solution of this problem. On the other hand the consistent use of the maximum weekly dose 0.1 r is, as a rule, not associated with any considerable difficulties, and may, therefore, be provisionally recommended until further results are available.

Some Constructional Details in the Protection of Full-Time Workers

In ordinary 200 kV roentgen therapy work the nurses and the technicians as a rule stay in the switch-table room during the treatment. It follows that this room must be particularly well protected, and that one of the most important parts of the protection is that sheltering this room. At the switch-table the amount of radiation must not exceed 0.1 r per week. From this, the maximum number of operating hours per day, or the weekly total may easily be calculated from the rate of leakage radiation actually observed (see the diagram in fig. 2). That rate is therefore very thoroughly examined at inspections. The same is done in rooms just below the treatment room, if permanently occupied by workers when the installation is operating.

The protective materials in walls, floorings, and ceilings must afford continuous protection, shielding the rooms adjoining the therapy room from the radiation. It follows that the joints of adjacent layers of protective materials in walls, flooring, and ceiling must be leakage-proof. Such leakage-proof joints are usually obtained by overlapping the layers. It is however, of great importance that such overlaps are sufficiently broad. The following rule, suggested by the author, has been used with good result: the width of an overlap shall not be less than the sum of the required thicknesses of the layers, increased by an amount of 2.5 times the distance between the layers in the overlap. The latter additional amount refers particularly to inspection windows of lead-glass provided with peripheral sound-openings, and to protective doors.

In doors, door frames, and lead-glass window frames, lead plate is mostly used as protective material. If lead plate is overlapped or covered with mortar, concrete, or barium-concrete, the lead should be coated with a solution or emulsion of asphaltum to protect it from corrosion.

As to the protective power of brick-walls, it should be remembered that the spaces between the bricks must be completely filled with mortar. Since this is not so in ordinary brick-work, it must be particularly specified, being of very great importance.

In modern Swedish hospital construction the main component of both flooring and ceiling is concrete, the average density of which is about 2.0. That material must, when used in ordinary 200 kV roentgen therapy installations, be at least 26 cm thick to be equivalent to 4 mm lead. By vibrating the concrete just after it has been poured into the moulds, its density can, however, be raised to about 2.5, and its thickness accordingly reduced. Concrete of this specification may also be used in protective walls.

In floorings where the protection required is not fully obtained by permanent components, the additional protection is usually obtained

by filling in the free space. If there is a sufficient vertical space, ordinary fine sand may be used, if the space is small, the additional amount of protection offered by the filling may be increased by using a mixture of sand and barium sulphate (4).

If the ceiling of a treatment room is next to the roof, and no particular protection would seem to be required, a study of any possible exit directions of both primary and scattered radiation is recommended, and it must furthermore be remembered that in past years roentgen therapy installations have developed towards higher electrical effects. In the author's opinion it may therefore be wise to provide for reasonable protection. When a building is under construction, the application of adequate protection in both flooring and ceiling is usually not costly, but is very expensive when the building is once completed.

Another very good protective material is barium-concrete. It is especially used to increase the protective power of brick-walls of insufficient thickness or density, and of ordinary brick-walls in which the spaces between the bricks are not completely filled with mortar. A surface layer of barium-concrete may then be applied to one or both sides of the wall. Their thickness depends on the required increase in protective power. If suitably prepared and of due proportions, the density of dry barium-concrete is 3.0—3.1, and for use in 200 kV therapy installations a thickness of about 6 cm may then be considered equivalent to 4 mm of lead. If the surface of a brick-wall is more or less uneven, the specification of a somewhat thicker layer of barium-concrete than that calculated may be recommended. In most cases the easiest way to get a leakage-proof joint between the barium-concrete and the protective materials of adjacent walls and floorings is to apply the barium-concrete in a single layer to the treatment-room side of the wall. It is not considered suitable to apply the watery barium-concrete to wooden walls; lead plate is then to be recommended. If barium-concrete alone is to be used as protective material, it is suitably applied to a supporting wall of ordinary porous bricks, 10 cm thick, or between two thin brick-walls.

Some Experiences from Inspections of the Protection

In a number of therapy departments parts of the protection have been found inadequate, in most cases, however, by no means seriously. In the following a brief account of some findings is given.

A few lead-glass inspection windows of only half the lead-equivalence required have actually been found, and some windows provided with sound-openings, required a broader overlap or other effective means to ensure a leakage-proof junction between the window and the surrounding protective wall.

As a rule the doors in the protective walls of treatment-rooms have proved the weakest part of the protection. Experience has shown that the greatest care is essential in the construction of the overlaps of hinged doors over the door frame and at the lock to get leakage-free protection. It has also clearly demonstrated that a hinged door without threshold is hard to get leakage-proof. A threshold providing sufficient overlap is consequently recommended as the most reliable design. To facilitate the passage of carriage-beds the threshold may suitably be rather broad, of moderate height, and well sloped on both sides of the door. The protective material in the threshold and frame is usually lead plate, which must be joined to the protective materials in the flooring and wall with satisfactory overlapping.

In some cases a dose-rate of 1×10^{-5} r per second has been found at the threshold of hinged doors, but only 1×10^{-6} at a distance of 0.5 m from the threshold. In such cases the rate of leakage radiation may clearly be considered harmless.

In a new department the door between the treatment room and the switch-table room was found to be equivalent to only 2.5 mm of lead instead of 4 mm as specified in the drawings. This observation clearly shows that errors may occur in spite of detailed specification.

Repeated inspections have clearly demonstrated that protective doors sliding along one side of a wall are particularly hard to get free from leakage. This type of door should therefore be avoided in therapy rooms. If they are used, great attention must be devoted to obtaining leakage-free overlaps between the door, the wall, and the flooring.

It may also be pointed out that all possible exit directions of both primary and scattered radiation through the ordinary windows of the treatment room must be carefully considered. The protection afforded by the distance from the source of radiation is mostly sufficient, but sometimes additional protection must be provided. Since the application of such an additional protection usually is rather expensive, it is wise to consider this question already in planning the therapy department. In concrete or brick buildings, outside walls usually offer satisfactory protection, provided they are of adequate thickness and density.

The risks of irradiation to the workers using a PHILIPS short focal distance therapy unit necessitate special provisions for their protection. In all treatments of this kind a protective shield should be used at the tube. Such a shield, 15 cm in diameter and equivalent to at least 1 mm lead, is both efficacious and convenient. Workers remaining in dangerous vicinity of the treatment field during the irradiation — *i. e.* in most cases less than two metres away — should wear lead rubber aprons and gloves. If the unit itself is handled with care, and these protective provisions

are competently used, the irradiation may be considered harmless to the workers.

Under unfavourable operating conditions the valve tubes of a high-voltage generator may emit roentgen rays. A dose-rate of 1×10^{-4} r per second has for instance been observed at a distance of 1 m from the valves of a constant potential generator operated at 165 kV and 15 mA. However, this radiation from therapy valves is not very penetrating. It is, for example, safely absorbed by walls of ordinary red brick, but, on the other hand, hard enough to penetrate thin walls of porous bricks or of wood.

The reason why such an unexpected source of radiation occurs is usually that the electron emission of the filament is too small in relation to the load current. In constant potential generators, for example, an emission 20 times greater than the tube current is usually considered safe. Yet, the author has seen valve tubes emitting radiation even when the electron emission was exactly 20 times the tube current, which has made him believe that a ratio not less than 25, or still better 30, is required for radiation-proof operation of properly designed valves in constant potential generators. It is in all circumstances of the greatest importance that valve tubes are operated at the proper filament temperature. Higher temperature than necessary shortens filament life, while too low temperature results in insufficient emission, which causes the anode to emit roentgen rays and overheat. The overheating may lead to a rapid destruction of the valve.

The most reliable way to eliminate the risk of producing roentgen rays in the valves is undoubtedly to use valves with over-sized filaments. Such over-powered valves may in particular be recommended for therapy generators fed by a line in which considerable voltage fluctuations are frequent. Such valves will probably also be more economical, as more operating hours will be obtainable from each valve.

In circuits for magnifying the potential delivered by the high-voltage transformer, the valves may sometimes be emitting radiation during the non conducting half-cycles. The radiation is then not excited by thermionic emission electrons from the filament, but by cold-emission electrons due to faulty design of the valve.

Protection of the Patients

The above discussion of the protection refers mainly to the workers. That part of the protection which bears upon the patients remains to be discussed. The general principle is then that each patient shall be satisfactorily protected from any radiation except that required for the treatment.

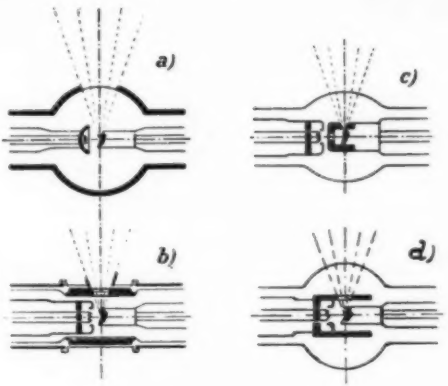

Fig. 7. Various methods of absorbing the roentgen rays in non-desired directions.

Primarily, this is obtained by enclosing the roentgen tube in a protective container only allowing the exit of the treatment beam. The protective material of the ray-proof enclosure of 200 kV tubes as a rule consists of, or is equivalent to 3 mm of lead. In addition to the thick-walled copper hood surrounding the focal tungsten target (see fig. 3 a), that amount has been found to offer satisfactory protection of the patient.

The following observations will illustrate this. A maximum of 8×10^{-6} r per second has been observed at the cathode end of the protecive containers, while the values are usually lower at the anode end. Around the filter holder, in the plane of the filter, values of 3×10^{-5} to 8×10^{-5} r per second have been observed at a distance of 0.5 metre from the centre of the beam. Values of 7×10^{-6} to 4×10^{-5} r per second have been recorded at the filter. All these values were obtained with closed shutter. The tube was operated at a tube-voltage of about 170 kV and a tube-current of 10—15 mA. Leakage radiation of such dose-rates is of no significance to the patient.

In a lecture in 1937 the author discussed the application of the protection. Various methods of absorbing the roentgen rays in non-desired directions were then demonstrated by means of a slide, reproduced in fig. 7. Particular stress was laid upon the fact that, from the point of view of reducing the weight of the protection required, it would be most efficient to arrange this as near to the focus as possible. The methods illustrated by c and d in the figure are conceivable for that purpose, but method c, in which the anode-hood itself provides the protection, is probably the most simple solution. Originally, the function of the anode-hood was merely to screen off the secondary electrons emitted from focus when the tube is in operation. By increasing its absorption power, it

may also be able effectively to screen off the roentgen rays in non-desired directions. Both methods would, however, imply a protection arranged in vacuum. The relatively high temperature used in the evacuation procedure may then be expected to limit the choice of material very much; lead, for example, cannot be used. In a recently published paper, COMBEE and FRANSEN (23) have now demonstrated a 200 kV tube in which the anode-hood consists of three layers, viz. an inner of copper, an intermediate of tungsten and an outer of a highly polished chromium-iron alloy. The protective power of this hood is said to be equivalent to 4 mm lead.

In this country we mostly use two means of protecting the patient against the beam beyond the outline of the field, viz. 1) pieces of lead rubber, and 2) cone-applicators. Both these, and their properties, have previously been discussed by the author (4, 10), and further particulars may be obtained from these references. In many cases of roentgen treatment, fields of relatively simple form and equal sizes are used. A moderate number of cone-applicators of appropriate shape may then meet all requirements. It may, however, be pointed out that the cover at the lower end of such applicators must be made of low-absorption material, and painted with a low-absorbing varnish entirely free from pigment.

If individually suited or more complicated fields are required for the treatment, we insert into the filter holder a plane lead-diaphragm, usually with a circular aperture, just giving a cross-section of the beam covering the desired field. The standard equipment of each 200 kV therapy unit includes three such interchangeable diaphragms corresponding to $^1/_4$, $^1/_2$ and $^3/_4$ of the maximum aperture. Beyond the outline of the field, the patient is covered with lead rubber sheets as required by the conditions. The lead rubber used for this purpose is of a specified thickness of about 2 mm, and a protective power equivalent to that of 0.7—0.8 mm lead. When filters of 1—4 mm Al are used, one or two layers of such lead rubber are put on the patient, and a transmission of at most 5×10^{-3} may then be expected. With copper- or tin-filters at least two layers are used, giving about the same protection.

If the field sizes are very small (a few cm^2 only) sheets of tin-plated lead, 0.7—1.5 mm thick, have proved very convenient. A hole of proper form and size is cut in the lead-sheet, which will then serve as a »mask» leaving the field free for treatment. The diameter of the incident beam is correspondingly reduced, for instance by an additional hole-diaphragm inserted into the filter holder. As a substitute for the tin-plating, the lead-sheets may be coated with the following solution: mastix 75, chloroform 100, aether 50, ol. lini 3.

Modern protective tube containers are usually provided with electrically operated shutters, arranged inside the filter holder just above the

filter. After some time of use, however, certain makes of shutter show an inherent disposition to lose their proper shape, obviously because they are made of ordinary soft lead. Such deformations impair the function of the shutter more or less, which may lead to accidents by undue irradiation. At the inspection of a 200 kV therapy installation we found, for instance, the shutter locked in the wide-open position, and it could not be closed by the operating switch. When the shutter was dismantled, considerable deformation could be seen, and this was the reason why the shutter had locked in the open position. In the protective enclosure described by the author (6), the shutter is made of »hard» lead, an alloy of 90 per cent of lead and 10 per cent of antimony, which has proved much more reliable.

Although not very frequently, the shutter is occasionally found not to open completely. When maximum field sizes are required, such a partial screening-off may cause incomplete irradiation, and hence lead to impaired treatment results.

Modern protective tube containers are also provided with filter-locks to prevent irradiation without additional filters. These locks may be mechanically or electrically operated. A lock of the first type, originally suggested by Prof. ÅKERLUND, is used in the container described by the author, and has proved to function reliably. The electrical type is, however, provided with a contact to prevent the shutter's being opened unless a filter is inserted. It has, however, been found that the filter may reach the contact position before it completely covers the maximum cross-section of the beam. This means that part of the cross-section would be left filtered through the filter-frame only. This being in many cases made of low-absorbing materials (iron or aluminium), the corresponding part of the irradiated field would be over-exposed when the copper or tin filters are used, and under-exposed when filters of 1—4 mm of aluminium are used.

On the basis of these experiences, it is considered necessary to test the function of the shutters and the filter-lock at the periodical inspections. This is done in the following manner. In place of the brass plate supporting the focal distance indicator, a lead lined brass-plate, provided with a wide hole covered with a fluoroscopic screen and a lead-glass of appropriate thickness, is inserted. This simple device allows convenient inspection of the efficacy and function of both shutter and filter-lock, and of the uniform distribution of the dose-rate over the whole cross-section of the beam, without irradiation dangerous to the inspector. In most cases such inspections only require relatively low tube-voltage and few milliamps; they are suitably made in the darkened treatment room.

Time and Staff Required for the Therapy Inspection

The periodical inspections are normally made by a physicist and an assistant, dividing the work between them as considered best by the physicist. The assistant as a rule connects and disconnects the instruments, except the secondary standard for dose-measurements, which is usually dealt with by the physicist himself. The installation is operated by the assistant, and the readings are taken and recorded by the physicist, who also makes the calculations required. Both of them are busy practically continuously during the inspection, including the time that must be devoted to personal discussions with the radiologist and his staff of nurses and technicians. The initial inspection of a 200 kV therapy installation takes on an average about $1^1/_2$ working-days, the second 6—7 hours, and each subsequent one about 4 hours. These times apply to an experienced inspector with a well-trained assistant.

From the above account and the statistical details of the work it may be easily understood that a qualified and experienced staff of physicists and assistants is necessarily required for the inspection work and for the further development of measuring methods and instruments. It should also be remembered that the training of each new member of the staff takes about a year; not until then can he be considered qualified for the routine inspections. Keeping in mind the development illustrated in fig. 1, inspectors and assistants must consequently be appointed a good while before they are actually required for inspection work.

The time taken by the routine periodical inspections of the therapy installations is at present 34 weeks a year. The laboratory work associated with the inspections, *e. g.* overhauling and calibration of the instruments, construction of control intensimeters, planning of the extensive travelling programs, etc., takes at least another 14 weeks. This means a total of 48 weeks a year. Besides that, a considerable amount of research laboratory work, *e. g.* the study and development of measuring methods and instruments, is undoubtedly necessary to maintain the highest possible standard and accuracy in the inspection work.

In the author's experience, the present conditions would require one physicist and one assistant to devote their time entirely to studies and development of measuring methods and instruments (incl. construction of control intensimeters) and to the roentgen therapy department of the Radiumhemmet. Besides that two permanent physicists and two assistants are needed for the routine inspection work and other work associated with this. That distribution of the present work would allow all members of the staff to keep in very intimate contact with the clinical work, and give them reasonable time for research, studies of current literature, and for calibration of their instruments. At present only two

physicists and two assistants are employed on the staff of the therapy inspection department. This is so far unsatisfactory as each physicist on an average must devote about 60 per cent of his time to mere routine work, resulting in a correspondingly reduced proportion of research work.

Instructions Suggested to Avoid Dosage-Errors in Roentgen Therapy Work, and to Protect Workers from Dangerous Irradiation

From the above account it will be understood that the main purpose of the periodical inspections is to secure the best possible physical safeguards from dosage-errors in therapy work, to prevent ill-health due to radiation among workers in the vicinity of the installations, and to give the patients reasonable protection from other radiation than is required for their treatment. The experience successively collected from the inspection work has clearly indicated a number of simple, yet for our purposes effective, measures. These are demonstrated at the inspections, and are being collocated in the form of General Instructions for workers employed in roentgen therapy work. A brief account of these is given below.

A. General duty.

The general duty of workers is to use the available protection in the most efficient manner, and to do their best to prevent ill-health from or accidents in the work.

B. Measures to avoid dosage-errors.

1) Check the zero-position of the instruments each day, while the installation is switched off. If this is not correct, adjustments must be made before the unit is operated. Tap the instruments gently with a finger when doing this. If a pointer then definitely changes its position in relation to the scale, the instrument is unreliable, and should be replaced. When the unit is in operation, be sure that all instruments continuously show the prescribed values: to do this satisfactorily, the operators should not simultaneously engage in other work.

2) As a matter of routine the dose-rates should be checked by the control-intensimeter at least twice a week, as well as whenever there may be any reason for extra check. If repeated readings differ by more than 10 per cent from the standards, the radiophysics laboratory must immediately be informed. The importance of sufficiently frequent checks may be easily understood from the fact that the radiation output from certain therapy tubes may fall off considerably relatively soon without other signs of disturbance.

3) The timer must be checked at least once a week by a reliable stop watch. This is done by setting the timer to five minutes in the usual way, and reading the treatment time released. If errors, irregularities, or disturbances are observed, the timer must be replaced or thoroughly adjusted, and then tested again.

Treatment times of less than two minutes should, if possible, be avoided. If such short times must be used, they must be timed by stop watch, and the operation partic-

ularly carefully adjusted. Timers ought to have clearly visible movement control, and the full scale should cover at most 15 minutes; if tube-currents not exceeding 8 mA are used, the maximum time may be 30 minutes.

If the timer is connected so as to operate the shutter at the beam exit opening of the tube container, the functioning of the shutter must be checked once a week. This is conveniently done by applying a fluoroscopic screen with lead glass at the beam exit opening. If the installation is provided with sound or light signals indicating the position of the shutters, these signals must also be checked. It is recommended to keep the treatment room dark, the doors closed, and with no admittance allowed during these tests.

Short focal distance therapy units should be provided with automatic cutting-out timers of types approved by the radiophysics laboratory. These must be checked as said above, using one or two of the most used treatment times. In units without such timers treatment times are checked by stop watch. If the treatment time is less than one minute, the operating conditions of the roentgen tube must be carefully adjusted to their proper values before the treatment is begun. During such tests the radiation must be screened off as said in section 19. All short focal distance therapy units must be operated with particularly great care in view of their extremely high dose-rates.

4) Before a treatment is begun, check once more that the right filter and the suitable diaphragm or cone-applicator are duly inserted, that the tube is adjusted to the correct focal distance, and that the timer is set to the time corresponding to the prescribed filter, focal distance, field size, and dose.

5) Do not rely on memory alone. Check that everything is in good order, and that adjustments and instrument readings conform as well as possible with those prescribed.

6) If there are any signs of parts or instruments of the installation not functioning reliably, any faulty part must be replaced or adjusted before the installation is operated. After each repair or adjustment, check the dose-rates by the control intensimeter.

7) When a therapy tube has been replaced, check by a fluoroscopic screen, at realtively low tube-voltage, that the dose-rate is uniform all over the maximum available cross-section of the beam and its boundary sharply defined. If not, the tube is probably not correctly centred in relation to the beam exit opening of the protective container. The dose-rate of the tube inserted is checked by the control intensimeter; the values read, the make, and the identification number of the tube are immediately forwarded to the Radiophysics Laboratory, and instructions awaited before the installation is operated. The particulars of previously operated spare-tubes were noted when they were inspected, and are thus immediately available.

8) When replacing valve tubes, check that the filament current of the new valve is adjusted to the value prescribed by the manufacturer. Each valve must be durably and distinctly marked with its normal and maximum filament current, the corresponding electron emission, and the maximum ratings of the roentgen tube when the valve is used in a constant and continuous potential circuit. After each valve replacement the dose-rates must be checked by the control intensimeter.

9) In some types of short focal distance therapy units a beam cross-section will be found in which the dose-rate more or less rapidly decreases from the centre towards the periphery. The most convenient way of eliminating this error is to use a permanent filter of a suitable material whose thickness at each point is adjusted to reduce by absorption the dose-rate to a constant value all over the cross-section.

C. Protective measures in operating 200 kV installations.

10) During irradiation of all kinds, including treatments, all doors of the treatment room must be completely closed and nobody admitted.

11) If the beam needs to be adjusted in relation to the patient during a treatment,

the irradiation should be discontinued by breaking the tube-voltage circuit before the treatment room is entered.

12) If a patient cannot be relied upon to keep quiet during the treatment, a sedative of re-assuring effect, administered at a convenient time before the treatment, may be considered. If the desired result cannot be obtained by such means, and the only thing to do is thus to hold the patient during the treatment, the »holders» shall be selected from the patient's relatives, or from people who have not been, are not, nor reasonably can be expected to become, employed in radiological work. Before beginning the treatment, effective measures must be taken to protect the person holding the patient from exposure to primary radiation from the tube and secondary radiation from the patient by making him use long lead rubber gloves (equivalent to at least 0.5 mm lead), as well as by covering him with lead rubber or some other material offering the same protection to the extent required.

13) Before each treatment, check that the cross-section of the beam is not larger than is actually required by the size of the treatment field. Outside the boundary of that field the patient must be reasonable protected against radiation from the tube. The material used to cover him shall have the protective power of at least 0.75 mm lead when filters of 1—4 mm aluminium are used, and at least 1.5 mm lead when the copper or tin filter is used.

14) When operation tests are made on ordinary therapy installations, the shutters at the beam exit opening of the tube enclosure, and the doors of the treatment room must be kept closed and nobody admitted.

15) Avoid directing the primary beam towards the wall separating the treatment room from the switch-table room.

D. Protective measures in operating short focal distance installations.

16) Avoid holding the tube by the hands. Use a stand, or a mechanical support, for adjusting the tube to its proper position.

17) If the tube must be held by the hands, those employed in the treatment who remain near the patient must wear long gloves and aprons, both of lead rubber with a protective power equalling at least 0.5 mm lead. See that none of them will be exposed to direct radiation from the tube, not even on thus protected parts of the body. Whenever possible, a protective shield of lead rubber or some other protective material, at least 15 cm in diameter, offering protection equalling that of 1 mm lead, should be applied to the tube, and placed as near the field as possible during the treatment.

18) During each treatment, the nurse or assistant operating the installation, must stay behind the switch-table, or even better behind a screen offering protection equalling at least that of 0.8 mm lead, and placed at least 1.5 metre away from the field in the direction opposite to that of the primary beam.

19) When the operation of an installation is tested, the beam exit opening of the tube enclosure shall be completely covered with 2 mm of lead, or its equivalent.

20) Remember that the dose-rates used are very high in short focal distance treatments, and that even a short exposure may accordingly be dangerous. Be always very cautious when operating such installations.

In concluding this account, I wish to thank most sincerely Mr. PAUL HAGLUND, the senior technician and assistant of this laboratory, who for a period of more than twenty years has with great interest and skill assisted me in the inspection work as well as in various kinds of laboratory work.

SUMMARY

This paper gives an account of the development, program, and organization of the system of periodical inspections of all roentgen therapy installations in Sweden. The main purposes of this system are to procure the highest possible physical safety against dosage-errors in therapy work, to prevent ill-health due to radiation in workers compelled to remain in the vicinity of the installations, and to give the patients reasonable protection from other irradiation than that required by the treatment. The account also includes various experiences from the inspection work.

ZUSAMMENFASSUNG

Verf. gibt einen Bericht über Entwicklung, Arbeitsprogramm und Organisation des Systems von periodischen Besichtigung der Röntgenbehandlungsanlagen, das in Schweden eingeführt ist. Der Hauptzweck dieses Besichtigungssystems ist, erstens, die beste mögliche physikalische Sicherheit gegen Dosierungsfehler in der Behandlungsarbeit zu erreichen; zweitens, der Entstehung von Krankenheiten durch Bestrahlung des Personals, das sich in der Nähe der Röntgenanlage befindet, vorzubeugen; drittens, dafür zu sorgen, dass die Patienten nicht einer anderen als der verordneten Bestrahlung ausgesetzt werden. Zuletzt werden Erfahrungen von der Besichtigungsarbeit mitgeteilt.

RÉSUMÉ

Cet article relate le développement, le programme de travail et l'organisation du système d'inspections périodiques des installations de radiothérapie tel qu'il est appliqué en Suède. Le but principal de ce système d'inspections est de procurer le maximum possible de protection »physique» contre des erreurs de dosage au cours des traitements, de prévenir des dommages, d'origine actinique, à la santé du personnel qui se tient au voisinage des installations de radiothérapie, et d'empêcher que les malades ne soient exposés à des irradiations autres que celles qui ont été prescrites pour leur traitement. Le rapport fait également état d'expériences provenant de ce travail d'inspection.

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FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

ON THE USE OF RADIOACTIVE SUBSTANCES IN SWEDEN, WITH SPECIAL REFERENCE TO IRRADIATION RISKS AND PROTECTION MEASURES[1]

by

Sven Benner

Other papers in this issue give accounts of the development and activities of the Institute of Radiophysics, especially in the field of radiation protection supervision, and of the various kinds of roentgen work in Sweden, so it is believed that an account of work with radioactive substances in Sweden might also be of interest. The subject is treated chiefly from the viewpoint of radiation protection, and some devices useful in this respect are described. The protection with particle accelerators is also briefly discussed.

The legislation in Sweden on these matters and the organization of the protection supervision are dealt with in other papers in this issue (SIEVERT 1, LARSSON 2), to which the reader is referred.

For convenience the subject is divided, somewhat arbitrarily, into the following sections: 1) Medical uses of radium and radon, 2) Medical uses of other radioactive substances, 3) Scientific and educational work with radioactive substances (including particle accelerators) and 4) Industrial work with radioactive substances.

1. Medical Uses of Radium and Radon

While the advent of large-scale nuclear physics work may eventually change the balance, radium therapy must still be considered the most important field of work with radioactive substances in Sweden. The bulk of this work is concentrated in the three central cancer clinics, Radiumhemmet in Stockholm, and the Jubilee Clinics of Sahlgrenska sjukhuset in Gothenburg and of the Hospital of Lund, while about 10 other

[1] Submitted for publication, Febr. 1, 1950.

Swedish hospitals, the most important of which are the General Hospital of Malmö and the Örebro Hospital, possess radium quantities ranging from 400 mg Ra down to very small amounts. In those hospitals possessing the smallest radium supplies, there are of course no possibilities to conduct effective radium therapy work.

Among the therapeutic methods used by the three central clinics, *teleradium therapy* plays an important part. Radiumhemmet has two units, one 3-grammes unit with pneumatic radium transfer previously described (SIEVERT 3) and one 5-grammes unit with mechanical radium transport (BENNER 4). The total number of teleradium treatments at Radiumhemmet is at present ca. 5,000 yearly. With the units formerly used (LYSHOLM 5, SIEVERT 6, 7), there were severe radiation risks to the personnel, among whom there was at least one case with important changes in the blood picture and severe impairment of the general health condition which, however, was considerably improved a few years after abandoning radiological work. In the old building of Radiumhemmet, there were also significant radiation risks in many adjacent rooms (BENNER 8). It should be noted that the »tolerance dose» believed to be safe at that time was much larger than the »tolerance dose» now usually accepted (9, 10) and the »safety dose» used by the Institute of Radiophysics in its supervisory work (SIEVERT 1). The risks to the personnel are considerably reduced in the new remote-controlled units and the radiation in adjacent rooms diminished to an insignificant amount by walls and ceiling of iron ore concrete (SIEVERT 11). Mirrors near the doors permit observation of the patients during treatments from a protected place at the writing desk of the control room. The teleradium department is located in the basement and is built on rock; effective protective walls could thus be constructed, irrespective of weight considerations.

Another device affording additional improvement of the protection was recently designed by the author. Its purpose is to immediately detect from the control room even slight movements, so easily occurring in the long-duration treatments, of the patient relative to the teleradium unit and thus to improve the accuracy of treatment, enabling the personnel largely to refrain from the frequent visual inspections formerly needed in many cases. The device consists of two small insulated platinum contacts protruding from holes a few mms. on either side of the centre of the teleradium unit portal. The contact pins are carried by thin phosphorbronze strips which hardly cast any shadow on the treatment field. The contacts are connected to a low-voltage D. C. source (the low-voltage secondary coil of a small transformer connected to a dry rectifier) in series with a relay which, when energized, breaks a circuit with an acoustical and/or optical alarm signal. A small circular tin-foil disk whose diameter slightly exceeds the distance between the platinum pins is

fixed to the patient's skin in the centre of the treatment field. Usually a trace of stiff vaseline on the back of the tin-foil is sufficient to keep it in place but with restless patients some kind of adhesive may be necessary. When the teleradium unit has been accurately directed to the patient, both contact pins will touch the tin-foil, the circuit through the relay will be closed and the alarm circuit will be broken. During treatment, if the patient moves laterally relative to the unit or if he draws himself back from contact with the unit, at least one of the contact pins will lose touch with the tin-foil, and the alarm circuit will be closed. With the acoustical alarm signal, an intelligent patient to whom the purpose of the alarm device has been explained can often himself adjust his position to silence the signal again. Separate switches enable one alarm circuit to be cut out when only the other one is to be used. In order

Fig. 1. Contact device for teleradium unit, seen from the inside. Centre, springs for the contact pins. Bottom left, contact plug for connecting the pins to the relay circuit.

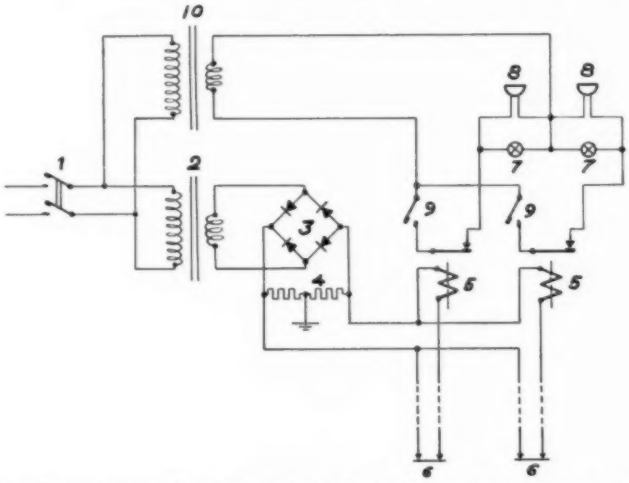

Fig. 2. Wiring diagram of a direction control device for two teleradium units. 1, mains switch, 2, transformer, 3, rectifier and 4, grounding resistance for relay circuit. 5, relays. 6, tin-foil disks and contact pins. 7, pilot lamps. 8, buzzers. 9, switches for cutting out either of the alarm circuits. 10, transformer for the alarm circuits.

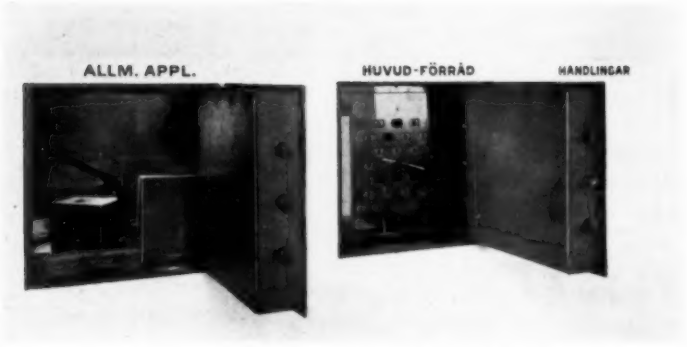

Fig. 3. Radium safes designed by SIEVERT. The right-hand safe is used for permanent storage of radium in drawers, to one of which the carrying handle is seen attached. Safes similar to the left-hand one are at the disposal of the wards for temporary storage of radium behind the lead block to the right, *e. g.* after removal from a patient during night hours.

to minimize the risk of electric irritation to the patient (when interrupting the relay coil circuit, a momentary tension several times higher than the D. C. tension might appear), the contact pins are shunted by a resistance too large to pass a current sufficient to energize the relay; the middle point of this resistance is earthed.

The Jubilee Clinics of Gothenburg and Lund possess each a 2-gm. teleradium unit with mechanical radium transport (BENNER 4). The units and the departments are, in the main, similar to those of Radiumhemmet.

Short distance radium treatments with surface application and with radium interstitially and inside body cavities are carried out extensively at all three Jubilee clinics. At Radiumhemmet the radium supply for this purpose is ca. 2.2 gms distributed into ca. 250 tubes, needles, cells, and planes ranging from 3 to 60 mg each. A description of the preparations at an earlier date has been given by THORÆUS (12). The total number of such treatments at Radiumhemmet is ca. 4,000 a year. The radium supply of the Jubilee clinics of Lund and Gothenburg, respectively, for these purposes, is ca. 0.8[1] and 2.1 g.

For intracavity treatments, especially in gynecological cases, radium tubes or needles with a wall thickness equivalent to ca. 1 mm lead are usually enclosed in applicators of different shapes (cylindrical, box-like, etc.) with a wall equivalent to ca. 2 mm lead, raising the total filtration to ca. 3 mm lead equivalent. See *e. g.* HEYMAN (13, 14). In surface applica-

[1] This figure is expected to increase considerably in the future.

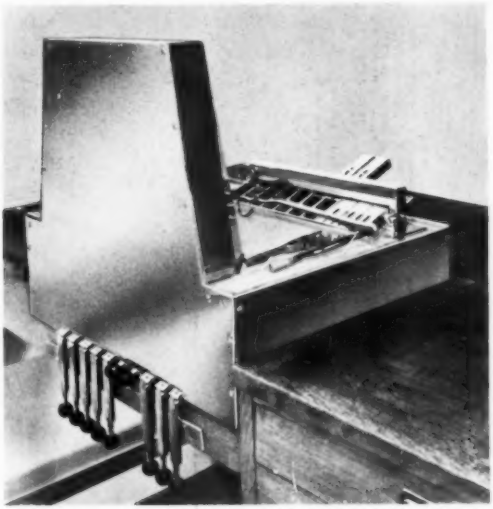

Fig. 4. Radium work bench designed by SIEVERT. Radium drawers have been inserted into the five right-hand channels, two of them being in the upper position with the radium accessible while the other three are down in the protected position. A couple of instruments for screwing the lids off and on lead filters are seen lying on the working surface.

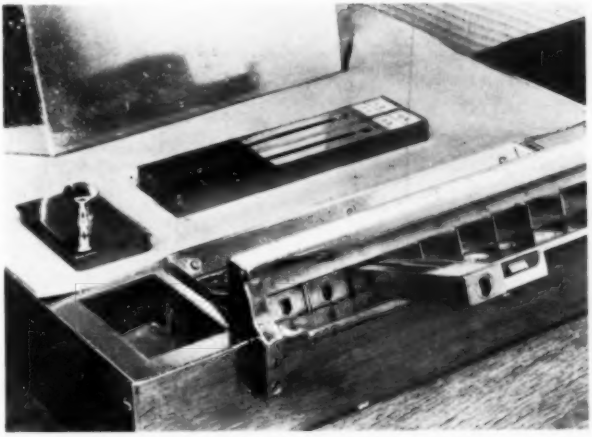

Fig. 5. Close-up view of radium work bench from behind. Two radium drawers are lying on the working surface. A lid seen below the radium drawers in the channels can be swung up and locked in position with the lock in the bottom right, when no drawer is pushed up. Bottom left, compartment for temporary storage of radium preparations, *e. g.* needles wich have been threaded.

Fig. 6. Hand-cart designed by SIEVERT with lead protection fitting the radium drawers.

tions, similar applicators are often used, while in other cases the small glass capsules described by STRANDQVIST (15) are applied.

Radium treatments of the types mentioned are attended by the well-known risks of radiation injuries to the personnel, both by local exposure of the hands and by general body irradiation. In order to lessen the latter risk, radium is stored within a heavy lead protection in a safe let into a wall constructed of the above-mentioned iron ore concrete (See Fig. 3). The radium supply is distributed in a number of small drawers fitting into rectangular channels in the lead block. The front part of the drawers being lead-filled, the radium is fully protected when the drawers are inserted into the safe. When the radium is to be used, the drawers are seized with a detachable handle and inserted into channels in the lead protection of a special radium work bench (Fig. 4—5). In a drawer inserted to the bottom of a channel, the radium is completely surrounded by lead; by aid of a rod manipulated from behind the heavy lead screen, the box can be pushed up so that the radium is accessible. Thus, only a small part of the radium supply needs to be in the unprotected position at any one time. The radium safe and work bench were designed by SIEVERT several years ago but have not been described previously. A lead-protected transport cart simultaneously designed to hold the radium drawers is shown in Fig. 6.

At Gothenburg, the radium safe and the drawers are similar to those of Radiumhemmet but the work bench is somewhat different (See Fig. 7—8). This type, designed by STRANDQVIST, is of a simpler construction than that of Radiumhemmet, but it will only accomodate 6 drawers as compared to 10 in the first-mentioned type. The Gothenburg type has the additional advantage of better protection to adjacent workers.

Besides during the making-up of radium tubes at the radium work benches mentioned, there is a considerable risk of general radiation injuries when applying the radium to the patients, especially in the

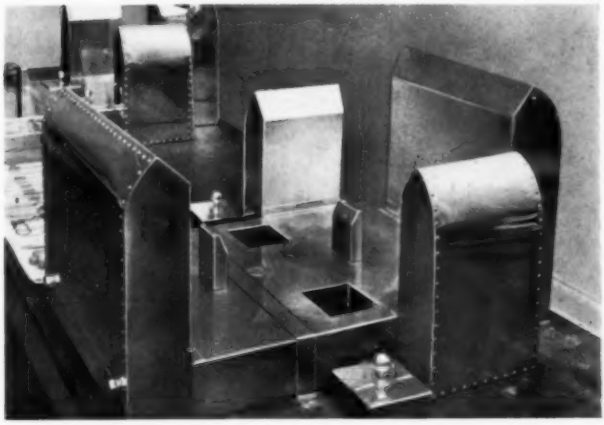

Fig. 7. Radium work bench designed by STRANDQVIST.

Fig. 8. Close-up view of the above radium work bench. In the upper left corner, lock for engaging the drawers in the protected position.

gynecological operating theatre, where the amount of radium is very large in the morning of treatment days but decreases as one patient after the other is given radium and is sent off to her ward. In order

Fig. 9. Radium transport cart designed by the author.

Fig. 10. Close-up view of radium transport cart.

to lessen these risks the author has designed a lead-protected hand-cart shown in Fig. 9—10. The radium, coming from the sterilization boiler in small stainless steel bowls, is distributed over three small platforms that can be raised or lowered by aid of levers, those bowls which are not needed at the moment being lowered beneath the edge of the lead protection. In order to attain good protection without an excessive weight of lead, the radium cart illustrated, which was intended to stand in a corner with its back and right-hand side facing heavy brick walls, was given a heavy lead protection (4 cms) only in the front and left-hand walls. A hand-bar used when pushing the cart from one room to another is attached to the left side which affords good protection. The bottom and lid contain only 1 cm lead, as gamma rays will have to pass obliquely through these parts before hitting personnel working near the cart.

For local transport, the author has also developed a hand-carried container embodying the same principle of economizing with the weight of lead (See Fig. 11). There is thus no lead in the part of the container

facing away from the person carrying it. In order to prevent its being carried with the wrong side facing the carrier the radium box is protruding from the lead protection (sloping to insure that the radium is down inside the lead). The protruding part of the box will strike the legs of anybody trying to carry the container the wrong way. Long leather straps between the container proper and its handle give distance and thus additional protection to the carrier's hand. The container is often used to transport to operating theatres radium tubes or needles sterilized together with some kind of holder for handling and inserting the radium; the protruding part of the radium box, otherwise empty, then comes in handy.

Fig. 11. Radium transport container.

Another protection problem arises in the wards where there may be simultaneously several patients to whom radium quantities of 100—200 mgs each, sometimes even larger quantities, have been applied. Here, not much is to be done except to prohibit the personnel to stay unnecessarily in rooms with such patients and especially near the patients' beds. Further, the task of nursing these patients should be distributed as evenly as possible among the personnel.

In order to reduce irradiation of the hands, various devices and gadgets are used, most of them well-known and rather self-evident, which need not be described here. A few of them might, however, merit mention. Needle eyelets are threaded by aid of a needle threader consisting of a loop of fine steel wire, attached to a long handle and pointed in its free end. Small lead blocks fixed to the radium work benches and drilled with holes fitting the most commonly used needles are convenient (See Fig. 7). In case cylindrical filters for radium tubes are to be threaded, a block with a correspondingly wider hole and a spring is used for keeping the filter in place during threading. For screwing lids on and off such filters, forceps similar to those previously described by HEYMAN (14, fig. 7, p. 35) are suitable. In order to avoid unnecessary handling, the packages of small glass capsules, according to STRANDQVIST (see above), are often substituted by perspex blocks in which a number of holes have been drilled at the same distance from each other and from the surface as in a package of capsules of the original type. Work unavoidably necessitating the close handling of radium preparations is as far as pos-

sible allotted to workers employed in radium work for a limited period only.

Other treatment techniques commonly used abroad, *e. g.* radon seeds and needles and large moulded applicators have only rarely been used in Sweden. In a few cases, a modification of LOMHOLT's (16) method of treatment with wax cakes containing absorbed radon has been applied successfully for large hemangiomas. The scale on which such treatments have been carried out is too small to warrant further consideration here.

In medical radium work, it is well known that a number of local skin reactions, mainly in the fingers, are unavoidable, and such cases occur in Sweden also, though an estimate of their number is difficult. Most cases are rather mild and subside after abandoning the dangerous work. Such severe cases of necrosis or radium cancer as those occurring in radium workers at the beginning of radiotherapy are not seen among those having entered the profession more recently. Except the teleradium nurse case mentioned above (p. 282), only few cases of significant blood changes have been observed.

2. Medical Uses of Other Radioactive Substances

For radiotherapy, other radioactive substances than radium and radon have as yet found only a very limited use in Sweden, though the situation may be radically changed in the future when more experience will have accumulated and suitable radioactive substances can be obtained in large quantities. As far as is known to the author, radioactive phosphorus has been used more systematically only at three Swedish hospitals for treating leukemia and other blood diseases. In a few cases, radioactive iodine has been given for thyroid diseases.

It seems to be very desirable that such treatments, in accordance with Swedish practice in radium therapy, are only given by radiotherapists specially trained in judging radiation reactions. It is also important for the doctor to have access to the services of a physicist experienced in nuclear physics measurements. This need is evident from experiences in our supervisory activity. The author has, for instance, seen the doctor in a county hospital give his patients P^{32}, having as an aid in his dosage a counting equipment which he believed to be correct but which was found on inspection to have such faults as to be practically useless, errors of several hundred percent being quite possible.

The risks to the personnel from external irradiation, from ingestion due to defective technique etc. being well known and dealt with at length by several authors (see *e. g.* PARKER, 17) on the basis of extensive investigations, the author will not comment further on this matter.

Work on diagnostic uses of radioactive isotopes, *e. g.* studies of the metabolism of different substances or of the blood circulation rate, is being conducted in Sweden on a somewhat larger scale than on their therapeutic uses. In the former type of work, smaller quantities of radioactive substances usually suffice, and the risks to patients and personnel are often negligible. For the above reasons, these risks will not be discussed here. The number of hospitals where radioactive substances are being used for diagnostic purposes is less than 10. The number is uncertain as the delimitation of medical diagnostics work from scientific research work is often rather arbitrary.

No cases of radiation injuries due to medical uses of radioactive isotopes in Sweden are yet known. Considering the short time such work has been carried on and the small scale of the present work, this is obviously no guarantee against future accidents.

3. Scientific and Educational Work with Radioactive Substances, including Particle Accelerators

One important type of scientific work with radioactive substances is that with pure gamma emitters (radium, mesothorium, radiothorium inside gas-tight filters absorbing all beta radiation; cobalt 60 etc.). Such work, in which the main risk is due to external gamma irradiation, is at present being conducted in 11 different institutions with quantities up to ca. 500 mg Ra.[1] The protection activity mainly aims at introducing remote-controlled devices with which the personnel can be afforded protection by long distances from the source and by heavy protection walls. In cases where certain adjustments or other operations indispensibly require close proximity of the operator, the experimental arrangement should be designed to enable him to perform these operations rapidly while preserving the accuracy needed. This is important when, as is often the case, local conditions prohibit the erection of a close shield heavy enough to permit staying without risk for a long time near the source.

Besides the above-mentioned laboratories there is at the Institute of Radiophysics a radon laboratory with a quantity of 1 gm Ra in solution. This laboratory has been designed for being operated as far as possible by remote-control from a completely protected operating desk. See also papers in this issue by SIEVERT (1) and EGMARK (18).

Scientific work with open radioactive preparations, being carried

[1] Some of the tubes contain a radium-beryllium mixture emitting also neutrons; their number is, however, too small to give a radiation risk comparable to that from the gamma rays.

out in ca. 30 different institutions, is very varied in character and scale from tracer experiments with small quantities of substance, in which minute amounts of activity are sufficient, to such work as fertilizer experiments on open land needing hundreds of millicuries. The risks are in the main the same as in medical work with radioactive isotopes (see above). A factor contributing to reduce the risks in many cases is that most instruments used in nuclear physics work are more sensitive than the human body. A careless scientist may therefore in many cases ruin his experiment by contamination of his instruments long before there is any risk to his health.

Work with particle accelerators of different types can, with regard to the irradiation risks, be divided into two phases, first, the actual accelerator running, causing the emission of radiation from nuclear reactions and/or roentgen rays, and, second, in many cases, subsequent work with radioactive substances produced in the nuclear reactions. The first phase is not work with radioactive substances in the usual sense of this word, but from the point of view of protection, it may conveniently be classed as such, the radiations emitted and the risks of radiation injuries being the same except for the addition of neutron radiation and the risks attended therewith. Formally, a reason for this classification may also be given by reckoning as radioactive substances of extremely short half-life the excited nuclei occurring as intermediaries in nuclear reactions. Roentgen rays excited by electron bombardment in certain accelerators are, in the supervisory work of the Institute of Radiophysics, for practical reasons treated in common with other types of radiation, thus avoiding having the same plant inspected by two different departments of the Institute.

At present about 10 Swedish institutions have accelerators such as cyclotrons, betatrons, synchrotrons, accelerator tubes excited by Van de Graaff or cascade generators etc. Smaller plants giving only insignificant irradiation risks are here disregarded. The protection problems are, for the first-mentioned phase of accelerator work, in principle the same as in work with strong gamma emitters, though the radiation level and the necessary protection measures may be on a much larger scale. Thus, Swedish cyclotrons are built in underground rooms separated by a great distance and thick layers of concrete and earth or water from control rooms and other adjacent premises. Most other accelerators are located in basements, thus enabling heavy protection walls to be erected. One Van de Graaff plant was, however, a few years ago erected on the first floor of a building and has given rise to difficult protection problems. Several adjacent rooms have to be vacated when the accelerator is running.

For the second phase of accelerator work, the protection problems are similar to those occurring in medical work with radioactive isotopes.

Because of the ever-varying character of scientific work and the provisional arrangements often adopted, a strictly centralised protection control is difficult to maintain with full efficiency. Preferably, at least the larger institutions should appoint among their employees one or more »protection officers» following the daily work more closely than can the supervisor from the Institute of Radiophysics. Discussions at the periodic inspections between the inspector and the protection officers, and the former's power to give regulations and instructions, or to propose regulations to be issued by the Royal Medical Board, should serve to maintain radiation protection throughout the country at a consistent and satisfactory level.

In educational work, the amounts of activity occurring are usually too small to imply noteworthy radiation risks. In the few instances where this is not true, that which has been said above on scientific work will apply.

No cases of severe injuries in scientific or educational work with radioactive substances in Sweden are known, probably from the same causes as mentioned above when discussing the medical uses of radioactive isotopes. Only a few instances of mild local skin injuries or a moderate blood reaction which has subsided after improvements in the protection conditions are known. These injuries, caused chiefly by carelessness and ignorance of the risks, occurred at the beginning of the supervisory activity before it had attained full efficiency. As this activity is being more perfected and a fuller knowledge of the risks and protection methods is being disseminated to wider circles, it is hoped that the increase in risks due to the rapidly growing scale of work will be counterbalanced.

4. Industrial Work with Radioactive Substances

Radium and radon quantities ranging up to a few hundred millicuries are being used in radiography of heavy iron structures and similar objects by a few Swedish establishments. In a shipyard, the possibility to introduce a radium tube into crowded spaces inaccessible to ordinary roentgen plants is especially valued. The exposure times being long, the number of exposures per day and the time spent in manipulating the radium are small. With suitable accessories such as a long pole for carrying the radium, the radiation risks are small if reasonable care is observed and a danger zone around the radium is vacated during exposures.

Another industrial use of radioactive substances is the luminising work in instrument factories. Such work is in Sweden being carried out in 15 different establishments, in most of these, however, on a small scale. Only in 5 of these establishments is there luminising work for one or a

few workers full-time or a considerable part of the working time. In these cases the usual protection measures — suction power ventilated hoods, cleanliness, prohibition during work hours to eat or drink (except from an approved drinking water fountain), inspection of the hands in ultraviolet light etc. — are prescribed. No certain cases of radiation injury are known, and a few persons in whom such injury was suspected have, upon measurement in this laboratory, been found not to have an accumulated radioactivity in their bodies significantly exceeding the normal. A more extensive series of such measurements is at present being prepared.

In two factories, large quantities of thorium salts are being handled in the manufacturing of incandescent mantles. In principle, the same protection measures are observed, though modified to the low specific activity of the material. The same applies to the processing, hitherto only on a limited scale, of the low-grade uranium deposits in Sweden.

One firm makes and repairs radium preparations for medical purposes. This work is conducted in close co-operation with the Institute of Radiophysics, where the radium is weighed in, the radium content is also measured and the preparations tested. The equipment and the protection arrangement used in filling radium preparations will be described in a forthcoming paper.

In two industrial laboratories, radioactive substances are being used in technical research work. That which has been said above on scientific work with open preparations will apply here also.

SUMMARY

A review of work with radioactive substances for medical, scientific, industrial and other purposes in Sweden is presented, stressing mainly the points of importance to radiation protection. Some devices designed at the Institute of Radiophysics, Stockholm, for improving the protection in radium therapy are described.

ZUSAMMENFASSUNG

Eine Übersicht über Arbeiten mit radioaktiven Stoffen für medizinische, wissenschaftliche, technische und andere Zwecke in Schweden wird mit besonderer Beachtung der Strahlenschutzfragen gegeben. Einige Vorrichtungen, die zur Verbesserung des Strahlenschutzes in der Radiumtherapie am Radiophysikalischen Institut, Stockholm, konstruiert worden sind, werden beschrieben.

RÉSUMÉ

L'auteur donne un exposé du travail en Suède avec les substances radioactives au service de la médecine, de la science, de l'industrie etcætera, appuyant spécialement sur la question de la protection contre la radiation. Il décrit aussi quelques instruments construits à l'Institut du Radiophysique de Stockholm dans le but de rendre plus efficaces les mesures de protection dans la curiethérapie.

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FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

ON THE POSSIBILITY OF PROTECTING THE LIVING ORGANISM AGAINST ROENTGEN RAYS BY CHEMICAL MEANS[1]

by

Arne Forssberg

The possibility to protect living organisms to a certain extent from the dangerous action of roentgen rays by means of chemical substances, injected, or in other ways brought into the organism, would only 10 years ago have seemed quite improbable. The conceptions of the action of ionizing rays then predominant were dominated by the hit theory which for one thing considers only direct hits on certain sensitive cell constituents and moreover does not leave much room for reversible and secondary reactions in the irradiated cell. A great many investigations of the action of roentgen rays on water solutions of chemical substances, including such important cell constituents as enzymes, as well as studies of roentgen effects on the nucleic acid metabolism *in vivo* have, however, cast doubt on the direct hit conception as a general explanation of the mode of biological action on living organisms (1—3). It can be maintained that a more chemical aspect of the radiobiological problems has developed. Renewed investigations during the last years on the roentgen induced mutations of *Drosophila* also seem to disprove the validity of the »one-hit» curve. In the work of BONNIER and LÜNING (4) the yield of a few definite mutations were found to be much lower with small doses (15 r) than predicted by the hit theory.

Especially the ability of certain substances to protect enzymes against the action of the rays suggests the possibility that this principle could be applied in irradiation experiments *in vivo*. Starting with the idea that substances which protect enzymes against inactivation by roentgen rays should also be useful in order to protect the whole organism from irradiation damage and death one has, however, to remember that all

[1] Submitted for publication, Febr. 1, 1950.

enzymes are not protected in the same degree, or at all, by the same substances. BARRON (5), studying the roentgen ray effects on a number of enzymes containing the sulphydryl (SH) group, found these enzymes easily inactivated by roentgen rays in moderate doses. The inactivation is due to an oxidation to the corresponding disulphide (S—S). The inactivation effect can be counteracted by the addition of other sulphydryl-containing substances (*e. g.* cysteine, glutathione) to the irradiated enzyme solution. Considering that enzymes of this type quite frequently occur in the organism it seemed likely that their protection in the living cells, if possible to realize, should also act in a protective way for the whole organism.

PATT et al. (6), working with rats have also found that cysteine, injected intravenously, in doses ranging from 175 to 875 mg. per kg. body weight, appreciably protected the animals from the effect of irradiation of the whole body (Dose: 800 r). It is quite consistent with the mode of action of the protecting agents that the substances must be given *before* the irradiation; it was also shown that cysteine given immediately after the irradiation was ineffective. The protective effects obtained by the authors are quite impressive. In a sequence of experiments some 75—90 % of the rats given 800 r died within 4 weeks when irradiated in usual way but only 10—20 % after an injection of the amino acid immediately before the roentgen treatment. The dose 800 r is obviously, however, chosen in a dose range where small dose changes in one direction or the other cause comparatively great changes in the death rate and where we consequently could expect to have the best chances for a protective effect.

The following short account will present some experiments on this problem. The bacteria *Propionibacterium pentosaceum, strain van Niel*, was used in some experiments bearing upon the mechanism of the protective action. In the second part preliminary experiments, applying the same principle on a more special problem; are reported.

Experiments on Propionibacterium Pentosaceum

Bacteria, grown for 2 days on Difco Yeast Extract—lactate agar slopes, were suspended in a solution containing 0.02 m lactate or glucose buffered to pH = 6.4 with phosphate or citrate. Cell number at the start $\sim 10^7$/ml. Cysteine in a concentration of 10^{-3} m of the total volume was added, then 15 min.—2 hours elapsed before irradiation. During this period no noteworthy cell division takes place as no growth promoting substances are present, but the cysteine is absorbed by the cells. Immediately after irradiation (Doses: 25—50,000 r) sterile flasks with 0.02—0.05 m glucose or lactate + 0.4 % Difco in 1/30 m

phosphate buffer pH 6.4 were inoculated (Cell number per ml. $\sim 10^8$) and the growth determined through counting in a Thomas chamber or by extinction measurements in a Beckman spectrophotometer.

Before starting a discussion of the results, some characteristics of the growth of this strain under normal conditions may be given. The general shape of the curves shows the common features of bacterial cell division and growth (see f. i. HINSHELWOOD (7)). The so called »lag time» is the time passing before a small inoculate, transferred into a fresh medium, enters into cell division. During this period an accumulation of substances may occur as also a reorganisation of the biochemical pattern of the cell before division can start. When cell division begins in due time it takes a logarithmic course, »the logarithmic growth phase», as long as foodstuff is in excess and the environmental conditions, *e. g.* pH, do not change appreciably or toxic products do not accumulate.

This means a regular cell division at a constant rate during this phase. Graphically this can be visualised through a plot of the log N/N_o values against time, where N_o is the bacterial number at the start of the growth and N the number at every measurement.

Principally one would expect an action of the irradiation in different ways. Firstly, there may be some influence on the processes going on in the lag phase, *e. g.* a retardation of any biochemical process previous to the cell division. This should be noticed through an increase of the lag. Secondly a certain number of bacteria are killed, some of them probably »at once», others may according to the view of LEA (8) die after one or two divisions as the result of a lethal mutation. Delayed division of part of the irradiated cells will possibly also occur.

The rather rough method of total cell counts applied, does not allow a decision between the various possibilities. One should here have to make viable counts of single cell plate cultures. For the purpose of visualizing the protective effect of cysteine the overall count will, however, do.

In Fig. 1 a single experiment is reproduced in the moment the cultures pass from lag to cell division. The lag time is very little if at all influenced by the irradiation as far as the possibility to judge goes. We may conclude that biochemical processes in the lag are not fundamentally checked. The unequal growth rates reflect, however, the roentgen effect and indicate that one or more of the events discussed above occur.

The cysteine protection is obvious and may be roughly estimated from the mean of a number of trials in the logarithmic growth phase. A small correction must sometimes be applied when the unirradiated controls with and without cysteine give different growth rates (see however below and Table 1). Often, as in the curve (▲) in Fig. 1, the slope is

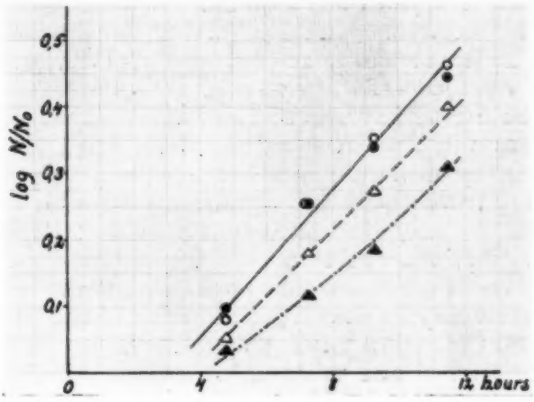

Fig. I. Increase in number of bacteria in beginning of logarithmic growth phase. Cysteine-treated, control (○); Normal substrate, control (●); Cysteine + roentgen (△) and normal substrate + roentgen (▲).

not truly logarithmic which should mean that delayed injurious effects remain. Average data from repeated experiments which have given consistent results are shown in Table 1.

Table 1.

Added substance:	Irradiated in:	Growth without irradiation in $\frac{\text{substrate + added substance}}{\text{substrate alone}}$	Protective effect ± %
cysteine	air	1.04	+ 45 ± 5.1
thioglycolic acid	»	1.05	+ 25 ± 5.3
» »	N_2	1.09	+ 46 ± 7.0
thiourea	air	1.00	+ 22 ± 2.1
urea	»	0.95	+ 2 ± 5.9
glycocoll	»	0.99	− 2.5 ± 5.2

In all probability the protective action in these experiments is a specific one depending on the presence of a sulphydryl group in the added substance. Some experiments were made using other SH-containing chemicals; in Table 1 are given the results when adding thioglycolic acid and thiourea under the same conditions as in the cysteine experiments. These substances were also found to give a slight but not so obvious protection as cysteine in the same concentration. As far as we know they are not a normal metabolite of these bacterial cells. It may probably be that the cells rapidly get rid of the SH-groups through

oxidation. When now the same experiments were made with bacteria cultivated under anaerobic conditions and if the irradiations were also performed under anaerobiosis, the protection of thioglycolic acid was increased and equalled that of cysteine. It is important to note that neither cysteine nor thioglycolic acid nor thiourea caused any decrease of the growth rate in the concentrations used. From the table we find that the average growth rate moreover shows a very slight increase (between 4—9 %, eventually not significant) after an addition of the said substances. We may then exclude a possible interpretation of the mechanism viz. that these substances in some way arrest the metabolism and the cell division processes, thus minimizing the effect of irradiation in about the same way as does *e. g.* a lowering of the temperature. The results support the assumption that all SH-containing substances which can be absorbed and tolerated by the organism, and which are not oxidized too rapidly should give a certain protection. In the cited investigation of PATT cystine, the oxidized product of cysteine, was also quite ineffective as a protection. Further evidence of the specific action of SH groups is that urea and glycocoll had no such effect as may be seen from the Table 1.

Local Application of the Protective Cysteine Effect

The experiments with bacterial cells seemed to indicate that it should be possible to apply the same principle when irradiating local parts of the animal or human body as the cysteine protection is obviously attained after a diffusion of the acid into the single cells.

A trial was then made on guinea pigs using the epilation as a criterion of the roentgen effect. Adult guinea pigs, weighing $^1/_2$—1 kg., were shaved and two equal roentgen doses were given on fields 25 mm in diameter on both sides of the back. The irradiations were given by 50 kV, total filtration around 0.2 Al, and with an intensity on the skin surface of 460 r/m. The dose measurements were made with a wavelength independent ionisation chamber [THORÆUS (9)]. The depth dose, *e. g.* 2 mm. and 5 mm. under the skin surface may be approximately calculated to some 80—85 % resp. 40 % of the surface dose [LAMERTON (10)]. This renders a rather local irradiation injury of the skin possible and minimizes unwarranted injury on more deeply situated tissues as far as possible.

The cysteine, buffered to pH = 6.4 with alkali, was injected intracutaneously before the irradiation in the amounts given below. Unbuffered cysteine solutions is injurious to the skin when administered in this way. A satisfactory distribution of the cysteine in the skin of the intended irradiation field was mostly obtained when injecting the solution at three or four points over the area to a total volume of 0.3

—0.5 ml. per field. Mild massaging of the field accelerated the distribution in the skin so that the small blisters disappeared swiftly. The irradiation was started within 5 min. afterwards and was finished $1^1/_2$—$3^1/_2$ mins. later. On the opposite (control) field physiological saline was injected in equal amounts and then processed as above. The cysteine and NaCl-fields were alternatively placed on either side of the back of the animals. Neither cysteine nor NaCl-injections caused any detectable damage on the skin per se.

Preliminary experiments showed that doses within 500—900 r caused partial to complete epilation but left the skin undamaged after the primary erythema. In the first series 8 animals were treated with cysteine on one field in a concentration of 1 mg./0.3 ml., the total quantity injected varying between 1 and 1.8 mg. per field. The roentgen doses varied from 700 to 950 r. In all instances a better hair growth on the cysteine treated fields could be registered, though in some instances not so pronounced. The general course of the reactions turned out as follows: some 24 hours after the irradiation a slight erythema developed on the fields with no difference whether cysteine- or NaCl-treated; the redness disappeared in a few days. The growth of the hair on the shaved and irradiated fields could be followed from the third day on. Some of the results in this series were especially interesting and may be interpreted with reference to Fig. 2. The right, NaCl-treated field, shows an almost hairless skin surface 10 days after the irradiation, the left cysteine-treated shows a surface with scanty hair growth, except on two round areas in the middle of the field, some 5 mm. in diameter, where a normally thick coat of hair has appeared. These two small fields are situated around two of the centres of the injections of cysteine. The explanation would seem to be that in these cases the cysteine had not been spread, giving a locally higher concentration of the amino acid with a better protection as a consequence. The same was found in two other cases in this series, indicating that the cysteine concentration could be safely increased all over the field in order to have a better protective effect.

Experiments with a cysteine concentration as above and higher roentgen doses, 1,200—1,600 r, failed to show any significant protection. After such doses the skin on both fields was markedly and so far (one month after the treatment) equally affected. By that time pronounced erythema, swollen tissue and small local wounds, healing with a thin, paperlike skin were noticed. Obviously the cysteine barrier was too weak to constitute a protection against the irradiation here but higher concentrations would possibly alter the picture.

In a third series the interest was concentrated on a study of the epilation by the constant dose 840 r and by an increased cysteine injection per field, between 2 and 5 mg. The results showed a more con-

oxidation. When now the same experiments were made with bacteria cultivated under anaerobic conditions and if the irradiations were also performed under anaerobiosis, the protection of thioglycolic acid was increased and equalled that of cysteine. It is important to note that neither cysteine nor thioglycolic acid nor thiourea caused any decrease of the growth rate in the concentrations used. From the table we find that the average growth rate moreover shows a very slight increase (between 4—9 %, eventually not significant) after an addition of the said substances. We may then exclude a possible interpretation of the mechanism viz. that these substances in some way arrest the metabolism and the cell division processes, thus minimizing the effect of irradiation in about the same way as does *e. g.* a lowering of the temperature. The results support the assumption that all SH-containing substances which can be absorbed and tolerated by the organism, and which are not oxidized too rapidly should give a certain protection. In the cited investigation of PATT cystine, the oxidized product of cysteine, was also quite ineffective as a protection. Further evidence of the specific action of SH groups is that urea and glycocoll had no such effect as may be seen from the Table 1.

Local Application of the Protective Cysteine Effect

The experiments with bacterial cells seemed to indicate that it should be possible to apply the same principle when irradiating local parts of the animal or human body as the cysteine protection is obviously attained after a diffusion of the acid into the single cells.

A trial was then made on guinea pigs using the epilation as a criterion of the roentgen effect. Adult guinea pigs, weighing $^1/_2$—1 kg., were shaved and two equal roentgen doses were given on fields 25 mm in diameter on both sides of the back. The irradiations were given by 50 kV, total filtration around 0.2 Al, and with an intensity on the skin surface of 460 r/m. The dose measurements were made with a wavelength independent ionisation chamber [THORÆUS (9)]. The depth dose, *e. g.* 2 mm. and 5 mm. under the skin surface may be approximately calculated to some 80—85 % resp. 40 % of the surface dose [LAMERTON (10)]. This renders a rather local irradiation injury of the skin possible and minimizes unwarranted injury on more deeply situated tissues as far as possible.

The cysteine, buffered to pH = 6.4 with alkali, was injected intracutaneously before the irradiation in the amounts given below. Unbuffered cysteine solutions is injurious to the skin when administered in this way. A satisfactory distribution of the cysteine in the skin of the intended irradiation field was mostly obtained when injecting the solution at three or four points over the area to a total volume of 0.3

—0.5 ml. per field. Mild massaging of the field accelerated the distribution in the skin so that the small blisters disappeared swiftly. The irradiation was started within 5 min. afterwards and was finished $1^1/_2$—$3^1/_2$ mins. later. On the opposite (control) field physiological saline was injected in equal amounts and then processed as above. The cysteine and NaCl-fields were alternatively placed on either side of the back of the animals. Neither cysteine nor NaCl-injections caused any detectable damage on the skin per se.

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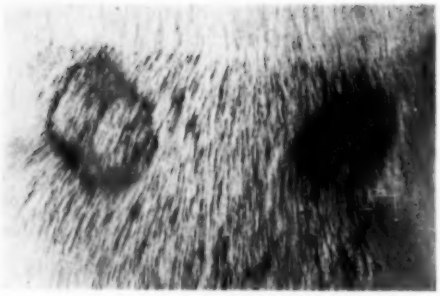

Fig. 2.

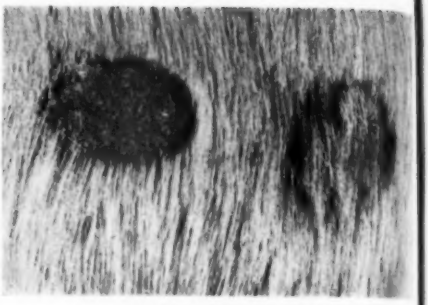

Fig. 3.

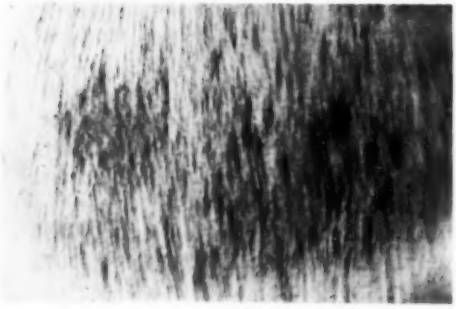

Fig. 4.

Fig. 5.

stant and pronounced protective effect without exception. In some cases we could register an almost normal growth of hair on the cysteine treated field while the control field was completely naked and the hair cells dead. In Fig. 3 such a case is reproduced. The left (control) field is naked and moreover shows in this case 3 weeks after the treatment some injury of the skin, the right, cysteine field, is coated except on the peripheral parts. The latter fact may be attributed to incomplete diffusion of cysteine from the centre and (or) to secondary radiation from the border of the lead shelter. Fig. 4 gives a picture sometimes obtained with individuals who are apparently more radioresistant. The coat grows fairly rapidly for some days on both fields but the shedding of hair sets in on the control field 5—6 days after the irradiation while on the cysteine field the roentgen effect is perceptible only on a few discrete points. The picture is taken 8 days after the treatment and shows epilation beginning on the left, NaCl field. In continued experiments the cysteine concentration was raised to 11 mg./0.3 ml. and the

total quantity on the field to 11—18 mg. The only visible effect of the irradiation on the cysteine fields was a slightly depressed growth rate of the hair (Fig. 5). A few weeks after the treatment the cysteine field (left) was almost impossible to distinguish from the surrounding coat, while the roentgen treated control fields were naked.

The fact that the cysteine injections immediately before the irradiation protect the hair follicles of the skin to a certain degree is then definitely established. The question how far this is possible must be left for further investigations to answer. Some of the outstanding problems are: the quantitative relation between cysteine concentration and protective effect and the suitable interval between injection and roentgen treatment as well as the possibility that even more serious damage may be partly prevented by the cysteine treatment.

The author is indebted to Mrs. B. Widjer and Miss V. Lindahl for their cooperation in this work and to the Knut and Alice Wallenberg Foundation for financial support.

SUMMARY

Attempts to protect living organisms against the effects of roentgen rays are reported. Cysteine, given to bacterial cells immediately before the irradiation, partly protects the culture from the irradiation injury. Other SH-containing chemicals act similar, but not related chemicals without a sulphydryl group. Cysteine, injected into the skin of guinea pigs, prevents epilation more or less after doses which without cysteine treatment result in epilation.

ZUSAMMENFASSUNG

Versuche, die darauf hinausgehen, den Organismus gegen die schädlichen Wirkungen der Röntgenstrahlung zu schützen, werden behandelt. Cystein, das Bakteriezellen unmittelbar vor der Bestrahlung gegeben wurde, schützt diese zum Teil vor Strahlungsschädigung. Andere chemische Verbindungen, die SH-Gruppen enthalten, wirken auf dieselbe Weise, nicht aber verwandte Verbindungen ohne solche Gruppen. Cystein, das in die Haut von Meerschweinchen injiziert wird, schützt mehr oder weniger gegen Epilation nach Strahlungsdosen, die ohne Cysteinbehandlung vollständige Epilation hervorrufen.

RÉSUMÉ

L'auteur traite des essais visant à protéger l'organisme contre les effects des Rayons Rœntgen. La cystéine administrée à des cellules bactériennes immédiatement avant l'irradiation les protège partiellement contre les dommages dus à l'irradiation. D'autres combinaisons chimiques contenant les groupes SH agissent de la même façon, mais non celles, même très voisines, qui sont privées du groupe sulphydryle.

La cystéine injectée par voie souscutanée à des cobayes les met plus ou moins à l'abri de l'épilation après des doses de Rayons qui sans le traitement par la cystéine provoquent une alopécie complète.

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FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

A SIMPLE INSTRUMENT FOR RADIATION PROTECTION MEASUREMENTS[1]

by

L. Lorentzon and *T. Wahlberg*

The instrument is built on photometric principles, the fluorescent light from a fluoroscopic screen being compared to the light from a field illuminated by an electric lamp. Similar methods have been used earlier as in, for example, the measurement of primary radiation from roentgen tubes (WINTZ and RUMP: Das Röntgenphotometer, Strahlentherapie 22, pp. 444—450, 1926) and in the so-called Auerdosiscope (ERNST, JAEGER and ZEILLER: Ein optisches Strahlenschutzmessgerät, Fortschr. Rtgstr. 70 (1944) pp. 123—127), where the light from a fluoroscopic screen is compared to two fields with a brightness corresponding to a dosage rate of 1 and 10 microroentgen per second respectively.

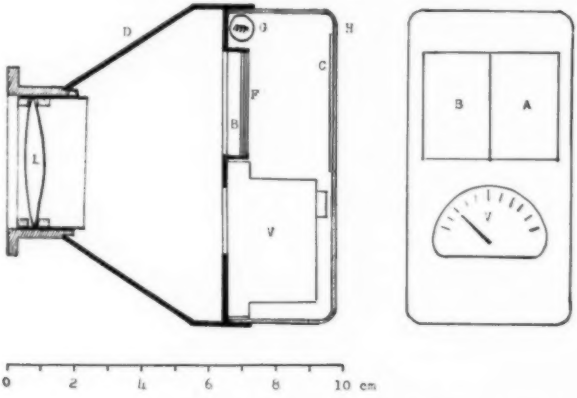

Fig. 1.

The design is shown in fig. 1, A being a highly sensitive fluoroscopic screen. Immediately next to this screen is placed a milk-white celluloid

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sheet B which is illuminated, through a colour filter at F, by the light from an electric lamp G which is reflected from a sheet of paper at C. The lamp G is so arranged that only light reflected from C can strike B. By means of a suitably distributed partial blackening of C (*e. g.* by aid of indian ink lines) an even illumination of B is obtained. The lamp, a miniature lamp of 2.5 volts and 0.1 amps., is connected to a small 3 volt torch-battery in series with a variable resistance of about 50 ohms. The voltage across the lamp is measured by the voltmeter V. With variations in light-intensity the tension across the lamp changes much faster than the current passing through it, and therefore measurement of the voltage has been preferred. To eliminate variable contact resistances the connections between the lamp and the voltmeter should be soldered. The instrument is built into a case, the back D of which is of aluminium. The front part H is made of a number of layers of paper stuck together by a waterproof adhesive, the total thickness being about 1 mm, which corresponds to a filtration of less than 0.05 mm Al; thus, radiations which are not too soft can penetrate without any appreciable absorption. In order to avoid any disturbing reflection of light, the inside of the cover is painted a dead black. The scale and pointer of the voltmeter are painted with a luminous compound, making them clearly visible to a well-adapted eye. The fluoroscopic screen, the comparison field and the voltmeter can be observed simultaneously through the lens L (+ 16 dioptrics), which can be adjusted for focussing. When measurements are being made the variable resistance is adjusted so that the same brightness is obtained on the fluoroscopic screen and the comparison field, and then the voltmeter is read off.

The fluoroscopic screen used is a type B 2 Patterson screen. According to HENNY and CHAMBERLAIN (GLASSER: Medical Physics. p. 1293, 1944) at 0.01 r per second with 60 and 80 kV (constant potential) the type B screen gives a brightness of 0.019 millilambert. Therefore, as the fully dark-adapted eye can see down to about 10^{-6} millilamberts, this screen allows the measuring of ray-intensities down to approximately 0.5 microroentgen per second. The new type B 2 Patterson fluoroscopic screen is about 40 % brighter, thus permitting the measurement of even lower dosage rates. Generally speaking, the brightness of the fluorescent screen can be considered proportional to the intensity of the roentgen rays striking the screen.

Colour vision begins at about 10^{-4} millilamberts, therefore, when greater brightnesses are to be measured, it is necessary to have the colour-filter F in front of the comparison field in order to eliminate colour differences between this field and the fluorescent screen. In the instrument under discussion this filter (F) is formed by a number of green gelatine sheets, the maximum transparency of which is at about 5,200 Ångströms.

(The wavelength range of fluorescent light from a Zinc-Cadmium sulphide screen is 6,000—5,200 ÅU, with a maximum intensity at 5,500 ÅU.)

The transmission of the filter has been chosen so that, with full loading of the electric lamp G (that is, at the maximum reading of the voltmeter), the brightness of the comparison field is equal to the brightness of the fluoroscopic screen irradiated by about 500 microroentgens per second. As the observer is exposed to the radiation during the measurements the instrument has been considered unsuitable for higher dosage rates.

Using an ionisation chamber, the instrument has been calibrated with the most usual radiation qualities met in radiation protection measurements (unfiltered secondary radiation from a wax phantom and heavily filtered primary radiation, at voltages between 40—150 kV). The results are shown in fig. 2 and table 1.

The instrument is also calibrated for γ-rays from radium and has proved to be about sixty times less sensitive to this type of radiation than to 100 kV roentgen rays.

When the quality of the radiation is known there is a measurement error of about 10 % for the highest radiation dosage rates and about 50 % for the lowest. Naturally, these errors are larger when the radiation quality is only estimated.

The instrument has been made mainly in two different types (see fig. 3), the type depending on the technique used. A small box containing the lamp battery and the variable resistance has been attached directly to the instrument itself. A suitable holder for protective rubber over-all goggles has been attached to one type of the instrument and, to the other, a well-fitting rubber eyepiece. The former type is more suitable if the observer wishes to keep his hands free whilst measuring and the latter enables, for instance, moisture to be easily removed from the observation lens.

Naturally, it is necessary to dark-adapt the eye for some time before taking measurements, and a good pair of adaptation goggles are most convenient for this. Using these, down to approximately 20 microroentgens per second can be measured after 5—10 minutes, even in full daylight. After an additional adaptation time of 5—10 minutes during which the eye has been completely screened from light, dosage rates of fractions of μr per second can be measured. An obvious great advantage in using this instrument is that the eyes can be adapted independently of each other.

The instrument permits the measurement of radiation dosage rates at a large number of points in relatively very short times. The accuracy of measurement is, in most cases, fully sufficient for protection measurements. Where more exact results are required the instrument is a valuable

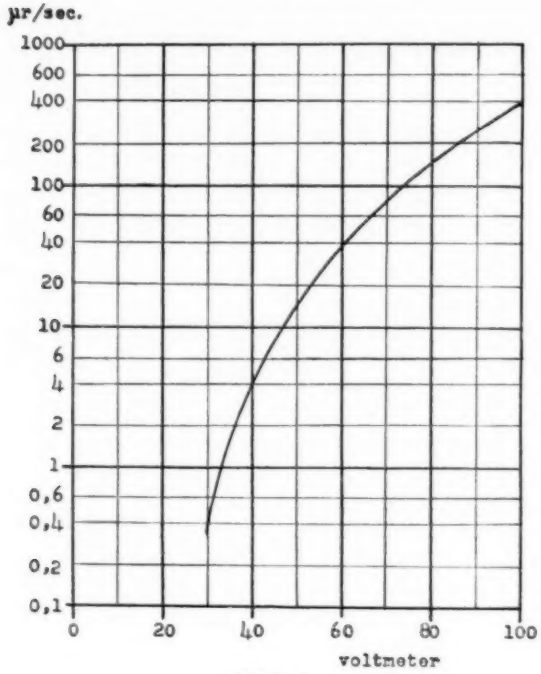

Fig. 2.

Table 1

Correction factor for radiation quality

Voltage kV	Unfiltered Secondary Radiation	Heavily filtered Primary Radiation
40	1.9	0,60
50	1.7	0,55
60	1.5	0,50
70	1.3	0,55
80	1.2	0,65
90	1.0	0,80
100	1.0	0,80
110	1.0	0,80
120	1.0	0,85
130	1.0	0,85
140	1.0	0,90
150	1.0	0,90

complement to, for instance, measurements with an ionisation chamber enabling a rapid preliminary survey in order to find those points where an accurate measurement is desirable. The instrument has proved to be very useful in detecting minor radiation leakages. Thus, as a direct

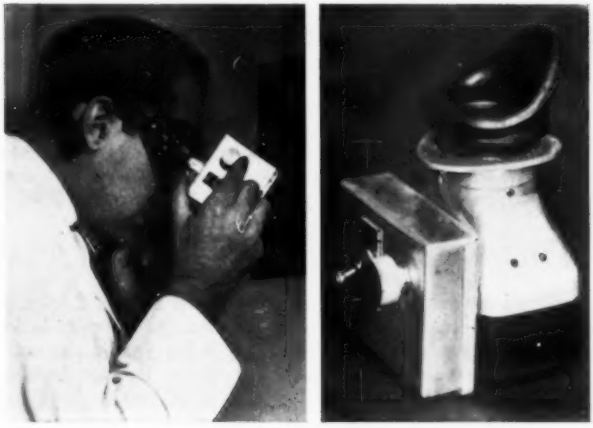

Fig. 3.

image of the leakage is obtained on the fluoroscopic screen and, as is often possible, the leakage is accurately localised (for example by placing a small metal rod in different positions in front of the instrument) this detection method not only enables the actual radiation dosage rate to be measured, but also provides information as to the best way of repairing possible defects in the protective devices.

The greatest demand for sensitivity of instruments measuring radiation intensities normally arises from protective measurements at roentgen installations being operated for a long time at low power (*e. g.* installations for therapy and roentgen fluoroscopy). Here it is possible to detect radiation doses of 0.1 r for a week[1] of about sixty working hours, assuming the lowest measurable dosage rate to be approximately 0.5 μr per second.

The instrument has even proved itself useful for estimating radiations of very short duration such as exposures of 0.05 seconds but, when possible, measurements at longer exposures are to be preferred.

SUMMARY

An instrument based on photometric principles for radiation protection surveys is described. The brightness of a highly sensitive fluoroscopic screen is compared with the brightness of a field lit by an electric lamp. Measurements are read-off on a voltmeter which measures the tension across the lamp. Dosage rates down to about 0.5 μr per second can be estimated. There is a measurement error of between 10—50 % depending on the circumstances prevailing at the time.

[1] 0.1 r per week is the »safety» radiation dose which the Institute of Radiophysics considers should not be exceeded for persons continually employed on radiological work.

ZUSAMMENFASSUNG

Es wird ein Instrument auf photometrischer Grundlage für orientierende Strahlenschutzmessungen beschrieben. Die Helligkeit eines hochempfindlichen Durchleuchtungsschirmes wird mit der Helligkeit eines von einer elektrischen Lampe beleuchteten Feldes verglichen. Das Messresultat liest man an einem Spannungsmesser ab, der die Spannung über der Glühlampe misst. Dosisleistungen bis herab zu 0.5 μr pro Sekunde können gemessen werden. Der Messfehler beträgt je nach den Umständen 10 bis 50 %.

RÉSUMÉ

Description d'un instrument photométrique pour la mesure d'orientation de l'efficacité des moyens de protection contre les irradiations. On compare la luminosité d'un écran fluorescent extrêmement sensible à celle d'un champ éclairé par une lampe électrique. Le résultat se lit sur un voltmètre relié aux bornes de l'ampoule électrique. On peut mesurer des doses de Rayons jusqu'à la limite inférieure de 0.5 μr par seconde. La marge d'erreur est de 10 à 50 % selon les circonstances.

FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

AN APPARATUS FOR RADON PURIFICATION[1]

by

Agnar Egmark

Many methods for purifying and collecting radon are described in literature. Some of them are mentioned in the references at the end of this article.

Dry radium salts occlude in themselves most of the radon that is formed, and it is practically impossible to remove it completely from them. Therefore they are unsuitable as a source of supply. However, if a radium salt is dissolved in a liquid the radon is distributed among gas and liquid according to Henry's law. At 20° C the radon concentration in water is one fourth of the concentration in the gas phase over water. Consequently it is possible to separate radon from a radium salt solution by pumping off the gas; this is the standard method for radon extraction.

HAHN and HEIDENHAIN (6) have used another substance for radon extraction: radium carbonate, very finely dispersed on a large amount of gelatinous iron hydroxide. This substance gives off up to 99 % of the radon.

From an aqueous solution of a radium halogenide a gas is evolved which contains one part of radon to about 500,000 parts of other gases. The chief problem in making radon samples is, therefore, how to separate the radon from the other gases. The gas consists mostly of hydrogen and oxygen, generated by radiodissociation of water. Besides water and hydrohalogenic acid vapours, free halogen and helium are present. If organic substances are present, carbon dioxide and other organic gases will also be developed.

The most common method for purifying radon is to oxidize the hydrogen to water and absorb the water in phosphorus pentoxide. Organic gases are oxidized to carbon dioxide and water. The acid gases are then absorbed by potassium hydroxide. For further purifying it is usual to

[1] Submitted for publication, Febr. 1, 1590.

solidify radon by cooling through liquid air, and to pump away remaining gases by means of a high-vacuum pump. There are variations of this method. O. WERNER (13) for instance, uses metallic calcium for absorbing both water and acid gases. Another method, chiefly physical, is assigned by ODDIE (2). At first he cools the gases by solid carbon dioxide to — 78°C. Then water, hydrohalogenic acid, and free halogen together with hydrocarbons become solidified and get low vapour pressures. Afterwards, radon and carbon dioxide are solidified by liquid air, and then hydrogen, oxygen and helium are pumped off by a high-vacuum pump. Finally the carbon dioxide is absorbed by fused potassium hydroxide.

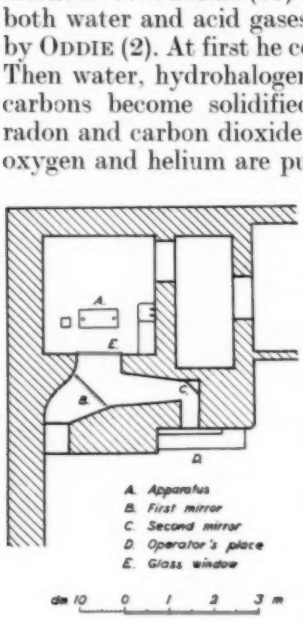

Fig. 1.

The designs of the purifying apparatus are commonly such that the gases are conveyed by Toepler pumps to and from the purifying equipments. The radon is finally collected over mercury or by freezing the preparation ampoule itself with liquid air. Instead of Toepler pumps, enclosed mercury diffusion-pumps are sometimes used to transfer the gas, when the pressure has become low enough through absorption of most of the gases by purifying substances. In Failla's apparatus (U. S. Patent No. 1,553,794, 1925) the Toepler pumps are of an automatic type. Here the mercury is forced upwards and downwards by an auxiliary vacuum over the external mercury surface and, at its highest and lowest points, comes into contact with platinum wires sealed into the glass. Electric currents through the mercury of the pump and the platinum wires cause the auxiliary vacuum pump to stop when the mercury in the inner part of the pump has reached its lowest level, and to start when it has reached its highest level.

A new principle for making radon samples is suggested by WOLF and RIEHL (11, 12). Using a dry preparation of the type suggested by HAHN and HEIDENHAIN, they have radon absorbed directly by charcoal without any purifying apparatus.

When the radon plant at the Institute of Radiophysics was planned the idea was to construct a remote-control apparatus which, as far as possible, could be operated from a protected spot and, moreover, would need the minimum of entry to the plant itself. The apparatus chamber was therefore built with thick concrete walls. From a separate control room a right-angled tunnel goes to the apparatus chamber. A horizontal periscope was constructed by means of two mirrors and the opening

in the wall of the apparatus chamber was covered with a hermetically sealed glass window (Fig. 1).

After studies of the different purifying methods, a modification of Oddie's method seemed to be preferable. With this modification no routine human intervention is needed in the chamber except for the changing of the ground-glass joint with the preparation ampoule, replenishing of cooling agents, and sealing-off the preparation. The glass stopcocks need not be operated manually as this can be done through remote control. If the gas is radically prevented from coming into contact with organic substances, carbon dioxide cannot be formed and thus, purifying with potassium hydroxide becomes unnecessary. Finally, by Oddie's method, it is not necessary to move the gas in the apparatus at a very low pressure, and at higher pressures the pumping speed is greater. The yield and purity of radon by this method are good.

If the radium salt solution consists of radium bromide dissolved in very dilute hydrobromic acid, we find the following premises for the purification of the gas according to this method: At — 78° C, the temperature of the solid carbon dioxide, the vapour pressure of water is 5.6×10^{-4} mm. Hg. The pressures of hydrobromic acid and bromine are small compared with this, since the acid is very dilute, and consequently the amount of free bromine is small. If the total gas volume to be cooled is 1 litre, the amount of vapour remaining in the gas is sufficient, when compressed to some c.mms., to be saturated at 20° C and to form a condensate. If high radon concentration is wanted it is advisable to subject the radon to a high pressure. If the preparation ampoule is made of glass which is to be sealed off by a flame it is necessary, however, to keep somewhat under atmospheric pressure. Radon, carbon dioxide, hydrogen, oxygen, and helium pass the cooler standing in solid carbon dioxide without being condensed. When the remaining gas is pumped into a vessel, part of the wall of which is cooled with liquid air, radon, carbon dioxide, and the remaining water vapour are condensed on the cold surface, the temperature of which is −180° to −190° C. Hydrogen, oxygen, and helium are not condensed, except for a very small quantity that follows the less volatile gases. If carbon dioxide is present its vapour pressure is so low that only a very small fraction of it is left in the gaseous state. The vapour pressure of the radon is not determined, since there is so little of the gas that the condensed layer is not even monatomic. During the whole process of freezing the gases mercury is deposited on the cold surface, covering the other condensed gases with a dense film of solid metal. Afterwards, when the vessel is emptied, this mercury layer prevents continuous evaporation of radon. After the evacuation, when radon is to be evaporated again, it is most important that the cooled surface is warmed up to a higher temperature than the other parts of the vessel,

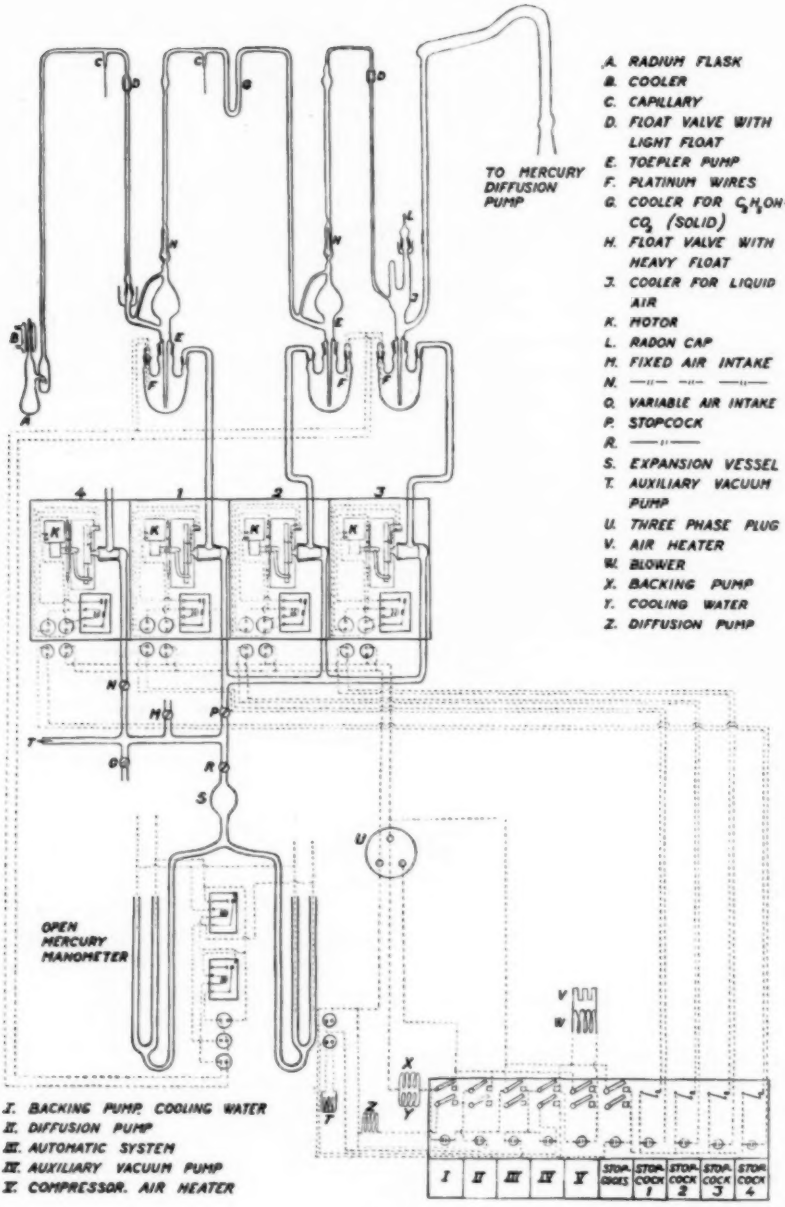
A. RADIUM FLASK
B. COOLER
C. CAPILLARY
D. FLOAT VALVE WITH LIGHT FLOAT
E. TOEPLER PUMP
F. PLATINUM WIRES
G. COOLER FOR C_2H_5OH + CO_2 (SOLID)
H. FLOAT VALVE WITH HEAVY FLOAT
J. COOLER FOR LIQUID AIR
K. MOTOR
L. RADON CAP
M. FIXED AIR INTAKE
N. —"— —"— —"—
O. VARIABLE AIR INTAKE
P. STOPCOCK
R. —"—
S. EXPANSION VESSEL
T. AUXILIARY VACUUM PUMP
U. THREE PHASE PLUG
V. AIR HEATER
W. BLOWER
X. BACKING PUMP
Y. COOLING WATER
Z. DIFFUSION PUMP
TO MERCURY DIFFUSION PUMP
OPEN MERCURY MANOMETER
I. BACKING PUMP. COOLING WATER
II. DIFFUSION PUMP
III. AUTOMATIC SYSTEM
IV. AUXILIARY VACUUM PUMP
V. COMPRESSOR. AIR HEATER
I
II
III
IV
V
STOP-COCKS
STOP-COCK 1
STOP-COCK 2
STOP-COCK 3
STOP-COCK 4

Fig. 2.

and for a sufficient time, so that all mercury distils back to the liquid surface; this can be done conveniently by a jet of warm air. Otherwise the underlying radon cannot evaporate, and consequently is lost. In order to separate carbon dioxide from the gas, potassium hydroxide is fused inside the apparatus. The potassium hydroxide must be fused in contact with the gas otherwise its outer layer becomes saturated with carbon dioxide, and the further absorption goes on very slowly. Water is formed during this reaction, which is also absorbed by the potassium hydroxide together with some of the water vapour of the gas. During all of these condensation processes there is no risk of supersaturation because of the strong ionisation.

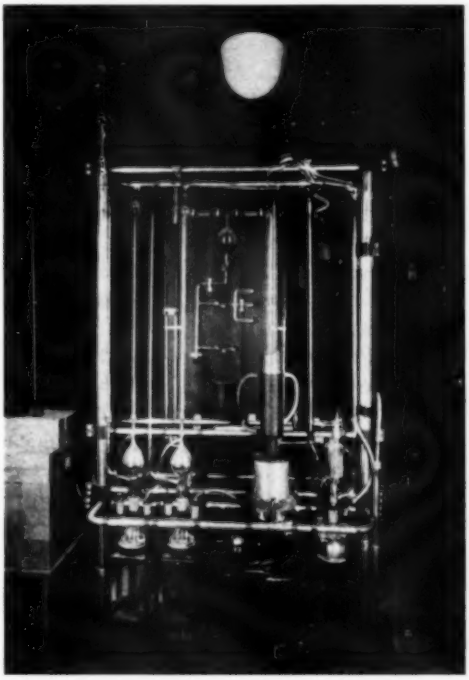

Fig. 3. Apparatus, seen from first mirror.

After constructional and experimental work the apparatus described in the following has been in action since the 15th of March 1949. The principles of construction are shown in Fig. 2.

The flask for radium solution is made of Thuringian glass. Pyrex and other hard types of glass are not suitable, since the radiation causes fissures in them. It is shaped like a Kjeldahl flask, the tube to the apparatus projecting from the side of the flask-neck. In its upper part the neck is shaped down to a narrow tube, sealed at its upper end. Round this tube is placed a cooler, to prevent continuous distillation of water into the apparatus, which the radiation heat developed in the radium solution would otherwise cause. The cooler is made of Pyrex glass (much less intensive irradiation) in such a way that water cannot pass into the radium solution, if the cooler should leak. In the flask there is 1 gram of radium, in the form of bromide, dissolved in 50 c.cs. of water very slightly acidified with hydrobromic acid. The acidity is intended to prevent alkaline precipitation. The flask is sunk up to its neck in soft paraffin-wax (melting point 40°—45° C) in a porcelain jar. Around this there

is a radiation protection screen, 10 cm. thick, built of lead bricks. The volume of the flask and the tube to the apparatus is about 300 c.cs. Assuming a solubility of radon in water of 0.25 at 20° C, when equilibrium has been obtained 95 % of the radon present will be in the gaseous state.

The tube to the apparatus is also made of Thuringian glass and is connected with it by a mercury sealed grease-free ground glass joint. Near the radium flask the tube is shaped to form a trap in order to prevent mercury from passing into the radium solution, should the glass in the apparatus fracture, and to prevent solution from splashing up into the apparatus, if the flask should burst. From the top section of the tube a short branch tube extends, that is terminated in a sealed capillary tube. When air is to be introduced into the apparatus a small section of this capillary-tube is broken off. Where the tube begins to descend towards the connection to the apparatus a float valve is built in, as a further measure of security that the mercury will not force its way towards the radium flask, should the glass in the apparatus fracture.

The apparatus is made of Pyrex glass. Of course, this glass is more radiosensitive than Thuringian glass but, on the other hand, it has greater mechanical strength and, since the active gas is pumped rapidly through the apparatus, the irradiation is not comparable to that experienced in the case of the radium flask. The main components of the apparatus are two Toepler pumps and two coolers. The Toepler pumps each have an upper and a lower section, the constructions of which are shown in Fig. 2. The upper section has a bulb with a volume of 300 c.cs., and directly over this is placed a float valve with a mercury-filled glass float, whose lower end is ground to fit into a narrow passage in the tube. The float is heavy enough to sink 1 cm. below the surface when floating on mercury. The lower section of the Toepler pump is a round flask of 500 c.cs. volume with three ground openings. The upper section of the pump is fitted with a ground core which corresponds with the central opening. This flask is nearly filled with mercury. The function of the pump is as follows: when the pressure in the upper section is lower than atmospheric pressure, the mercury in it is at a higher level than in the open lower section. At a sufficiently low pressure the mercury stands over the float valve. If now, an auxiliary vacuum is placed over the lower mercury surface, the mercury in the upper section will descend. The float valve becomes filled with mercury, and prevents gas from streaming down into the bulb from the tube above it. If the mercury continues to descend a vacuum will ensue in the bulb, and when the mercury has descended sufficiently gas will stream from the left tube over to the bulb. If the mercury in the upper section is then allowed to rise again, the passage from the left tube will be closed and the amount of gas that has passed into the bulb from the tube is forced up past the float valve. By repeating the

procedure it is possible to effect a controlled gas movement from the left tube to the tube over the float valve. Since the volumes of the radium flask and the pump are equal, the pressure in the flask is reduced by half with every stroke of the first pump. In practice it is reduced more rapidly for, at differences greater than about 10 mm. Hg between the pressures in the left tube and the tube over the float valve, gas passes directly through the bulb. The tube over the float valve leads to the first cooler. Between this valve and the cooler a branch tube with capillary leads off, so that air can be introduced into this part of the apparatus but not into the radium flask. The first cooler is immersed in a mixture of alcohol and solid carbon dioxide, and is shaped like a »corrugated» U-tube. The volume of the cooler plus connecting tubes is about 200 c.cs. From this cooler gas is pumped by the second Toepler pump to the liquid air cooler. From the proportions of the volumes it appears that the pressure in the first cooler will be reduced to $^2/_5$ by each stroke of the second pump. The tube to the liquid air cooler tapers off at its highest point to a 2 mm capillary tube, and is provided with a float valve in order to prevent mercury from running backwards. The liquid air cooler is mounted over a mercury flask of the same type as the lower sections of the Toepler pumps. The cooler is a double-walled vessel, which, in its centre, has a deep cavity, which is filled with liquid air. At its top the cooler carries a mercury-sealed, grease-free ground glass joint, on which the preparation ampoule is placed. 7 cm. below the tube from the second Toepler pump a wide tube leads off to a two-stage mercury diffusion pump. This diffusion pump has a capacity of 10 litres per sec. at a pressure of 10^{-3} mm. Hg, and as backing pump it is provided with an oil pump. Between the diffusion and the backing pump there is a hand-operated stopcock. The function of the cooler is as follows: At the commencement of the purification procedure the mercury surface in the cooler stands slightly above the mouth of the tube from the Toepler pump. This position can be effected by regulating the pressure in the lower flask. In the cooler the pressure is as low as possible. When gas from the Toepler pump is forced into the cooler, the surface of the mercury sinks below the mouth of the tube. Radon, carbon dioxide, if any, and residual vapour are solidified at the cooled part of the wall of the cooler. The tube from the Toepler pump is ventilated through the up-and-downward movements of the mercury in the tube over the pump. When all the gas has been pumped over into the cooler, and sufficient time has elapsed to allow all the radon to freeze, the pressure in the lower flask is decreased. Then the mercury surface in the cooler falls, leaving a free passage to the diffusion pump, and the cooler is evacuated. After this the pressure in the lower flask is raised again, so that the mercury in the cooler reaches its higher level and blocks up the tubes to the Toepler pump and diffusion pump. After

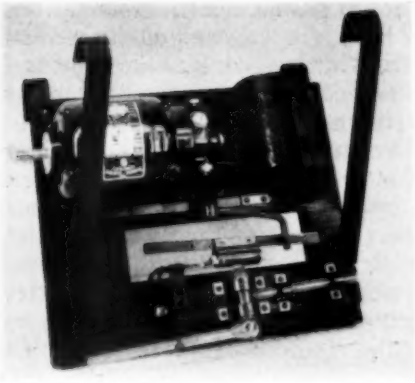

Fig. 4. Motor-driven stopcock.

the liquid air has been evaporated, and the cooler has been warmed by hot air, the pressure in the lower flask is raised still further, the purified gas being compressed in the preparation ampoule, which is sealed off.

At no time does the radioactive gas come into contact with organic matter. Before the apparatus was mounted, all parts were thoroughly cleaned. When operation commenced it was expected that residual traces of organic matter would give rise to carbon dioxide in the gas, and this was verified by tests with fusing potassium hydroxide, cf. ODDIE, which diminished the volume of purified gas. Tests made from November 1949 show that the reduction of the volume after fusing potassium hydroxide is very small, however. Preliminary experiments showed that it is unsatisfactory to lubricate the ground glass joints of the mercury flasks with grease. Even if only a thin layer of grease is used, it is imposaible to avoid the grease spreading over the glass and mercury surfaces snd forcing its way between them into the upper parts. Instead the ground glass joints were lubricated with pure graphite and sealed with Apiezon wax of medium hardness. This prevents impurities from entering the apparatus.

In order to construct an apparatus on these principles, remote-controlled and as far as possible automatic, a motor-driven glass stopcock and a system for effecting a periodically varying vacuum were constructed.

The motor-driven stopcock is shown in Fig. 2 and Fig. 4. It is of a type that requires a 180° turn to fully open or close. At the head of the stopcock is a metal casing fitted with a plate spring. The motor is provided with a double worm-gear that reduces the speed to 60 r. p. m. To the axis is attached an arm that drives the plate spring. The axes of motor and stopcock are eccentric in relation to each other, to the extent that at a given point the arm passes outside the spring. The function of the stopcock is as follows: a current impulse from a push-button causes a relay to function thus starting the motor. The relay is kept locked by a current through a locking-circuit, which includes a spring circuit-breaker. The arm attached to the motor axis turns the stopcock. When it has turned 180° the arm releases the plate spring, and the stopcock ceases to turn

immediately. At the same time the spring circuit-breaker is opened by a gadget on the motor axis, and then the relay breaks the current to the motor. Owing to its inertia the motor continues to turn to the extent that the spring circuit-breaker is closed again, but this does *not* cause the relay to function again. Often the spring circuit-breaker is adjusted so that the circuit is broken the moment before the arm loosens its grip on the blade spring. If the motor has a tendency to turn a large angle after the current has been broken, it is easy to couple it so that the relay, when open, short-circuits it. At a fresh impulse from the push-button the motor is turned 360°, and the stopcock 180°. At the head of the stopcock another spring is fixed which influences a small spring circuit-breaker, so that a small electric bulb is lit when the stopcock is open. The effect of this construction is that the stopcock becomes independent of the inertia of the motor, and stops immediately it has reached its correct position. Further, the plate spring is of such a shape that it is bent if the stopcock should happen to be stiff so that the stopcock cannot be broken by the motor. This construction may be varied in many ways, for instance by having the motor itself influence a circuit-breaker instead of using a relay. In fact, this construction was used in the first model, but the use of a relay was found to be more practical.

The apparatus for effecting a periodically varying vacuum consists of an oil pump, called an auxiliary vacuum pump in the following, plus the construction sketched at the bottom to the left of Fig. 2. This construction consists principally of two relays, a work relay and a safety relay, two open mercury manometers with iron contacts in the mercury, three separate air-intakes, and a motor-driven stopcock, 4. Via three parallel motor-driven stopcocks, 1—3, the apparatus is attached to the lower sections of the Toepler pumps and the flask under the liquid air cooler. In each of these flasks there are two platinum wires which dip into the mercury when it has reached a certain level. The platinum wires are connected in parallel with the safety relay. The function of the apparatus is as follows: The fixed air-intake M is adjusted so that the auxiliary vacuum pump can reduce the pressure in the apparatus to about 100 mm. Hg, if the two air-intakes N and O are closed. When this is done and if there is a high vacuum above them, the mercury surfaces in the upper sections of the Toepler pumps and in the cooler are just below the entries to the lowest branch tubes. When the auxiliary vacuum pump is at rest, the mercury levels in all shanks of the manometers correspond and are so high that even the high-level iron contacts in the left manometer dip into the mercury. If now the circuit-breaker for the automatic system is closed, a current passes through the left-hand manometer and the windings of the work relay. The relay begins to function and the auxiliary vacuum pump starts. When the relay is functioning,

there is also a current passing through the right-hand manometer and the windings of the relay. The pump reduces the pressure in the apparatus and the mercury sinks in the outer shanks of the manometers. As a result of this the current through the left-hand manometer is broken, but the relay remains in function, owing to the current through the right-hand one. When the pressure is decreased so much that the contacts in the right-hand manometer no longer dip into mercury, the relay is disconnected, and the auxiliary vacuum pump stops. Through the air intake M the pressure is again raised in the apparatus. The contacts in the right-hand manometer again dip into the mercury but since the circuit through them and the windings of the relay are connected in series with the relay itself, the relay does *not* function. When the pressure has risen so much that the contacts in the left-hand manometer again dip into the mercury, the relay functions and starts the auxiliary vacuum pump and the procedure is repeated. If, now, this pulsating system is connected with the lower section of a Toepler pump it is possible, by adjusting the stopcocks P and R and the iron contacts, to bring the apparatus and the Toepler pump into the same rhythm so that the Toepler pump makes a complete stroke with the apparatus. With suitable adjustment the action is chiefly dependent on the air-stream velocities and not on the static pressures. In this way the rhythm is almost independent of the variations in atmospheric pressure but on the other hand depends on air temperature. The apparatus chamber is heated thermostatically and the temperature kept constant at 20° C. This automatic system makes it possible to avoid sealed-in contacts in the radioactive parts of the apparatus.

Certain other gadgets are connected to the automatic system. There is a separate circuit-breaker to the auxiliary vacuum pump so that the pump can be driven non-automatically and without being influenced by the automatic system. The platinum wires which, at a certain level, dip into the mercury in the lower sections of the Toepler pumps and in the flask under the liquid air cooler, have the task of preventing gas containing radon from issuing into the lower sections. If the pressure in the upper section of a Toepler pump should be greater than about 150 mm. Hg, the auxiliary vacuum pump can bring down the mercury level there to such an extent that gas bubbles over to the lower section. Before this happens, however, the platinum wires will make contact with the mercury causing the safety relay to function and, if the auxiliary vacuum pump is operated by the automatic system, the pump will stop. Air streams in through M, and the mercury level in the upper part rises. The auxiliary vacuum pump does not start until the mercury has reached the iron contacts of the left-hand manometer. In order to bring about the transference of gas in the apparatus as rapidly as possible, the plati-

num wires are adjusted so that they will come into action if the pressure in the upper section is greater than about 10 mm. Hg, and, with automatic pumping, this will happen before the mercury in the right-hand manometer sinks below the iron contacts. In such a case the automatic pumping takes place in such a way that the auxiliary vacuum pump starts up on an impulse from the left-hand manometer and stops when the mercury in a Toepler pump reaches the platinum wires. If the pressure in the upper part of the apparatus is low the gas flows more slowly into the pump bulbs. In this case the safety relay does not respond. The mercury sinks in the upper sections of the apparatus and remains standing at its lowest level till the right-hand manometer stops the auxiliary vacuum pump. The apparatus is adjusted so that the passage from the left-hand tube to the pump bulb is open for about half-a-minute during each pumping stroke.

In the cooler the platinum wires have also another function. If so much gas has been forced into the cooler that, if the amount of gas were increased further, part of it would bubble into the tube to the diffusion pump before sufficient time has elapsed to solidify all the radon, the platinum wires make contact with the mercury and stop the automatic pumping. Then, after a sufficient interval, the cooler is evacuated and the pumping can proceed. With 1 gram of radium in the apparatus this partial evacuation is hardly necessary.

In the automatic system there are two more air-intakes N and O. In N there are two stopcocks, one manually operated and one motor-driven, 4. This intake N is intended to maintain the mercury in the liquid air cooler at its higher level immediately above the mouth of the tube from the Toepler pump. When the motor-driven stopcock is open, the manually operated stopcock is adjusted so that the mercury will stay at the level required when the auxiliary vacuum pump is working. If the motor-driven stopcock is closed, the mercury sinks to the level corresponding to the intake M. The adjustment of the manually operated stopcock need not be altered again. In this way a remote-controlled mercury seal is obtained, by which the passage to the diffusion pump can be opened or closed. This seal is free from organic matter. Consequently the active gas only comes into contact with the solution, glass, and mercury. A stopcock between the diffusion pump and backing pump prevents air from flowing back through the mercury seal when the backing pump is not working. The variable air-intake, O, is used when the mercury surface is to be maintained at a certain level as, for instance, when the preparation ampoule is a ball and the connecting capillary-tube is to be sealed off below this ball.

The complete apparatus obtains its power through *one* three-phase outlet, and can be cut-off from this, if the plug is pulled out. Most of

Fig. 5. Control table and operator's view of the apparatus.

the apparatus is made up of separate, easily exchangeable parts, which can each be taken out of the apparatus chamber when necessary, *e. g.* for repair. Only the tube system for the active gas is a permanent fixture and this is joined together in one piece. From the apparatus chamber all wires to the control room at first pass out into the open air and then into the control room. This is in order to prevent radon from diffusing into other parts of the building. The control table is shown on Fig. 5 and to the right at the bottom of Fig. 2, and its arrangement will be evident from the diagram.

Operation of the Apparatus

Evacuation

At the commencement of operation atmospheric pressure prevails in the inner and outer sections of the apparatus. The evacuation of the apparatus is performed in the following way: The motor-driven stopcocks are closed. The stopcock between the diffusion pump and backing pump is opened. The auxiliary vacuum pump is started by the separate circuit-breaker. The backing and diffusion pumps are then started and mercury begins to rise into the upper sections. By opening and closing the motor-driven stopcocks, 1, 2, and 3, the mercury levels in the upper sections are made to coincide so that air has free passage and so that the

flow of air does not exert too great a pressure on the mercury in the tubes and float valves. After a few moments the flow of air becomes steadier, and then the mercury surface in the liquid air cooler is fixed at its lowest level. The platinum wires of the cooler are then disconnected from the safety relay, stopcocks 1 and 2 are opened, and the automatic system is started. The Toepler pumps rapidly diminish the pressure in the radium flask and the first cooler. The first Toepler pump must not operate too long, in order to avoid unnecessary loss of water. When the pressure in the radium flask has reached the vapour pressure of the solution, and consequently stops decreasing, stopcock 1 is closed, the mercury in the pump being at its highest level. The second Toepler pump is left in operation till no more bubbles are forced up through the float valve. Stopcock 2 is closed, and stopcock 4 opened. When the diffusion pump has evacuated the cooler completely the auxiliary vacuum pump is started, and stopcock 3 is opened at the same time. The mercury rises to the higher level described above, and then stopcock 3 is closed. The auxiliary vacuum pump and the diffusion pump are stopped and the evacuation is then complete. The backing pump and cooling water are left running until the diffusion pump has cooled, and the stopcock between the backing and diffusion pumps has been closed.

Preparation making

When the solution is standing in the apparatus, gases are evolved. As was said before, these gases mainly consist of hydrogen and oxygen. The gas evolution is considerable. A hydrous solution of 1 gram of radium in radiation equilibrium evolves 50 c.c. of gas at 760 mm. Hg and 0° C every 24 hours. The mercury level in the tube from the radium flask to the apparatus sinks, and from this the amount of radon present can be approximately estimated.

In order to make a preparation the following method is used: At first the backing and diffusion pumps are started. They must be given time to attain maximum effect, *i. e.* a pressure $< 10^{-6}$ mm. Hg disregarding mercury vapour. The pressure can be checked by evacuating the liquid air cooler, and then allowing the mercury to rise into the preparation ampoule. From the pressure in the ampoule and the volumes of the cooler and ampoule the degree of evacuation can be calculated. Other arrangements for vacuum measuring are unnecessary. Alcohol and solid carbon dioxide are mixed in a Dewar flask, and the flask is placed so that the first cooler sinks into the bath. The mercury surface in the liquid air cooler is adjusted at its higher level and the cavity of the cooler is filled with liquid air: pumping can then begin. Stopcocks 1 and 2 are opened and the automatic system is started. The two Toepler pumps are synchronized. The active gas from the radium flask is forced by way

of the solid carbon dioxide cooler to the liquid air cooler. After 6 strokes of the pumps, stopcock 1 is closed, the mercury surfaces now being at their highest level, and then the first Toepler pump ceases to work. The second Toepler pump is allowed to go on for 4—5 strokes more. After this the automatic system is stopped, and stopcock 2 is closed, the mercury in the respective pumps being at its highest levels. The liquid air cooler is evacuated in the way described above, taking about 1—5 minutes, depending on the original pressure in the cooler, and is then shut off from the pump again. Hot air is blown into the cooler and stopcock 3 is opened. Then the mercury rises in the cooler. In order to prevent the mercury rising too rapidly, it is advisable to run the auxiliary vacuum pump for short periods only. If necessary the mercury level below the ampoule is regulated by means of the variable air intake O. The preparation is sealed off, and the procedure is complete. In order to remove the small residual quantities of radon from the apparatus, the mercury in the cooler is drawn down to its lowest level, so that the cooler again communicates with the diffusion pump. The Dewar flask containing alcohol and carbon dioxide is removed, and the second Toepler pump is used automatically so that both the coolers and the pump itself are washed with vapour. All water need not be pumped off from the first cooler for, when the next preparation is to be made, the Dewar flask is placed round the respective cooler, while the liquid air cooler is evacuated, and the second Toepler pump is operated automatically till all vapour is either frozen or pumped off by the diffusion pump. Usually 4—5 pumping strokes are enough for this purpose.

Changing the preparation ampoule

When a new preparation ampoule is to be placed on the apparatus, it is most practical to do this so long after making the foregoing preparation that the activity of the apparatus, and consequently the irradiation to which the operator is subject is as small as possible. This time can easily be determined by measurements.

The mercury in the second Toepler pump and in the liquid air cooler is pumped down to its lowest level. In the float valve of the Toepler pump there must be a good mercury sealing. A ground joint that connects the backing pump with the tube to the diffusion pump is opened. The stopcock between the backing and diffusion pumps is slowly opened, so that air passes through the diffusion pump into the liquid air cooler. Then the mercury level falls in the cooler. When all mercury has sunk down into the lower flask, stopcock 3 is opened by an extra push-button near the apparatus. Now air flows into the flask and forces mercury up into the cooler. Then the stopcock between the backing pump and the diffusion pump is opened fully so that air streams in rapidly, the mer-

cury in the cooler sinks back, and atmospheric pressure prevails in the cooler as well as in the flask. A new preparation ampoule is put on, the ground glass joint at the backing pump is put on, stopcock 3 is closed, and the airfilled parts of the apparatus are evacuated again. When the ampoule is being changed, air fills the cooler and tube up to the float valve of the second Toepler pump, which prevents it from diffusing farther.

Irradiation to which the operator is subject

The occasions during which the operator has to remain in the apparatus chamber on routine work, are the following:

1. Changing the preparation ampoule.
2. Setting the Dewar flask and opening the stopcock between the backing pump and diffusion pump.
3. Filling with liquid air.
4. Sealing off the preparation ampoule.
5. Removing the Dewar flask.
6. Closing the stopcock between the backing and the diffusion pumps.

Furthermore, he is exposed to radiation when sealing the preparation into the external covering tube.

At the daily making of preparations a trained operator will receive a total radiation dose of ~ 2 mr during the work-periods described above. Some examples of doses received: During 1. 3 mr were received, the radon content of the apparatus being 500 mC, and at another time 5 mr for 700 mC. In the latter case 15 mr were received at Σ 2—6 and the extra sealing in, as well as the adjusting of the level with the air intake. Thus the total dosage when making preparates with 700 mC in the apparatus is in this case 20 mr. 700 mC are the radon production for a week. At Σ 2—6 and extra sealing in, with a radon content of 300 mC, 1—2 mr were received. These doses are measured in the left upper waistcoat-pocket with a pocket electroscope, calibrated against a known radium preparation. When special operations are to be carried out, such as relubrication of the stopcocks about twice a year, the irradiation will be much greater, but much of this work can be done by persons who are not otherwise employed in radiological work. Since the apparatus is mainly built of removable parts, most of these operations can be effected in another room without irradiation risks.

Results

A detailed account of the results will be given later on in another article. It seems, however, as if the percentual yield is in good accordance with Oddie's results. For smaller quantities, 100—200 mC, the yield is

more than 90 %, which slowly declines with increasing quantities to about 80 % at 500 mC. The purity of the gas is not yet completely determined, but it seems to have a maximum for quantities of about 300 mC. However 50—100 mC/c.mm. have been received after one freezing of radon, and more than 100 after two freezings and evacuations from this quantity of radon without using potassium hydroxide or other chemicals. These values are corrected to 760 mm. Hg and 20° C.

SUMMARY

In the article a radon purifying apparatus is described, which involves only physical methods. The apparatus is of a semi-automatic type and is operated from a protected location so that the irradiation to which the operator is subject is very small. It is mainly constructed of removable parts. There are no stopcocks or other movable parts to impede the radioactive gas, and the gas does not contact any other substance than the solution, glass, and mercury. The constructions of a motor-driven stopcock and a system for effecting periodically varying pressures are also described in the article.

ZUSAMMENFASSUNG

Es wird über die Konstruktion und Handhabung eines Radon-Apparates berichtet, der nur mit physikalischen Reinigungsmethoden arbeitet. Der Apparat ist semi-automatisch und von einem geschützten Platz aus manövrierbar, wodurch die Bestrahlung des Operateurs sehr gering wird. Er ist hauptsächlich mit auseinandernehmbaren Teilen konstruiert. In dem Weg des radioaktiven Gases sind keine Hähne oder andere bewegliche Teile, und das Gas tritt mit keinen anderen Materialien als die Lösung, Glas und Quecksilber in Berührung. Die Konstruktionen eines motorgetriebenen Hahns und eines Systems für pulsierende Drücke werden auch beschrieben.

RÉSUMÉ

Un appareil pour purification de radon par des méthodes exclusivement physiques est décrit. L'appareil est semi-automatique et est manœuvré d'un endroit protegé ce qui rend l'irradiation sur l'opérateur minime. Il est en grande partie construit de pièces démontables. Il n'y a pas de robinet ou d'autre pièce mobile au passage du gaz radioactif, et le gaz n'entre en contact qu'avec la solution, le verre, et le mercure. L'auteur décrit également les constructions d'un robinet à moteur et d'un système pour effectuer des pressions périodiques variées.

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FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

A ROENTGEN APPARATUS FOR INTENSE ROENTGEN RADIATION OF SHORT DURATION INTENDED FOR BIOPHYSICAL RESEARCH WORK AND FOR SPECIAL TREATMENT PURPOSES[1]

by

Rolf M. Sievert

There are many occasions when it is of great importance to be able to work with extremely high dosage rates in, for instance, research on the action of roentgen rays on biological objects of different kinds, in the testing of radiation instruments, and in the treatment of malignant tumours. Equipment for intense radiation has hitherto been constructed mainly for industrial work and therefore gives either a very small useful dosage with one discharge, or a high dosage only within a very constricted volume. The methods used are also based on principles which do not allow variation of the anode type according to the different requirements.

In the design of the roentgen apparatus and the tube described below the choice of the size and shape of the anode is an important part of the problem. The effective area of the target must be as great as possible, because of the high thermal load which accompanies the discharge, and at the same time the surface has to fulfill certain other demands. The question posed in the present case has been: What form shall the target take; 1) in order to give a dose distribution most favourable for deep therapy and 2) for research work on biological objects (mice and rats) and testing of ionization instruments where a comparatively great volume is to be uniformly irradiated? Since one of the greatest difficulties in deep therapy is to protect healthy tissue surrounding the tumour from too strong irradiation, it is desirable in the former case to be able to concentrate

[1] Submitted for publication, Febr. 1, 1950.

the radiation on the tumour. Some preliminary results of attempts to obtain a concentrating effect are given in another paper in this issue.[1]

In the Institute of Radiophysics an establishment for the purposes just mentioned has been constructed which will be described in this article.

The High Voltage Laboratory

Special premises have been built for the apparatus which consists of a COCKCROFT and WALTON high voltage generator for a maximum voltage of 1.2 million volts (1 in Fig. 1), a condenser battery (2—5), a roentgen tube (6) and a large storage battery for heating the filament of the cathode. The control arrangements (7—9) of the machinery have been made to fit the demand of specialized routine work and are therefore somewhat special. Attention has been paid to the need for safety precautions to prevent accidents due to the presence of a high voltage condenser.

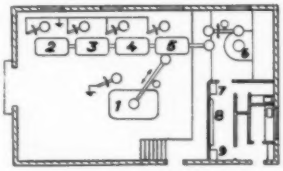

Fig. 1.

Drawings of the premises are reproduced in another article of this issue.[2] The building has a floor area of 19 × 11 meters and a ceiling height varying from 9—11 meters. In one corner there is a gallery with a control room, a dark-room, and a room for the preparation of biological objects. In the corner near to the gallery there is an irradiation room with walls of iron ore concrete,[3] 40 cms. thick. The insulated part of the roentgen tube and the filament current leads are placed above the ceiling of this room.

In order to gain sufficient distance to the ceiling, the high voltage generator is sunk about 1 m. into a cavity in the floor. Beside this cavity, under the floor, there is a space intended as a future irradiation room for a discharge tube, connected either to the present generator or to a VAN DE GRAAF apparatus in a pressure tank.

In the laboratory walls, which are of facade bricks, there are strong fittings with threaded apertures, bricked in at about every square meter. These permit the fixing of requisite manoeuvring wires, ladders, observation platforms, or other arrangements. The roof, which rests upon three beams of reinforced concrete, is supplied with telpher guides and a number of steel girders, from which may be hung connecting rods and measuring apparatuses for high voltages. The telpher guides are placed

[1] LINDELL, SIEVERT and WAHLBERG (Acta Radiol. 33, p. 344, 1950).
[2] SIEVERT (Acta Radiol. 33, p. 191, 1950).
[3] SIEVERT (Acta Radiol. 14, p. 597, 1933).

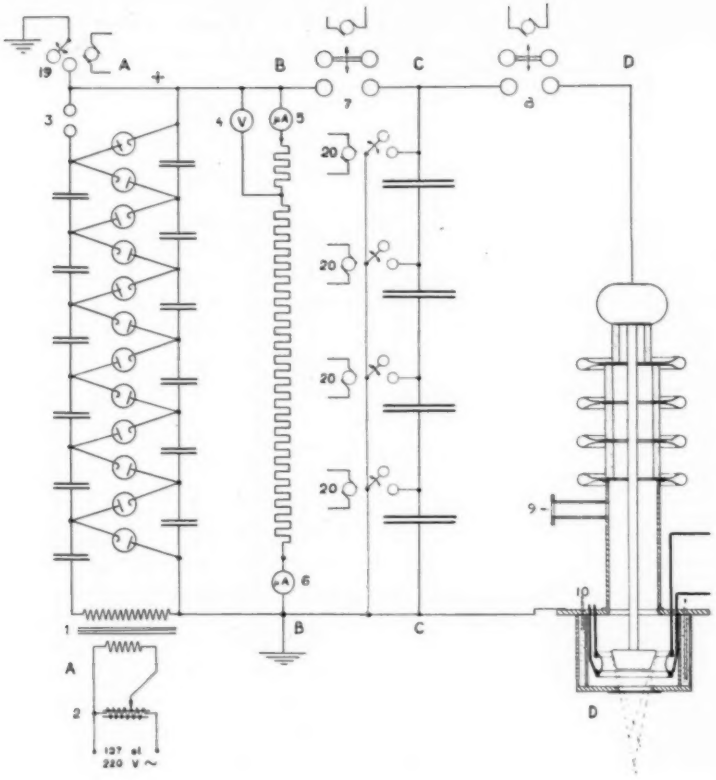

Fig. 2.

so that the motor driven telpher car (for 1,000 kgs.) can be used in practically all possible assembly positions. The windows are supplied with motor driven dark-room blinds. Over the windows fluorescent lighting is installed, supplied by cables lying free from the walls. For other electric cabling there are spacious cable-ducts in the floor. The floor is strongly reinforced and the reinforcement is, like a number of electrical contacts in the floor, connected by thick copper wires to large earthing plates. The heating is from normal central heating radiators, and the ventilation is assisted by a strong fan. The walls, floor, and ceiling of the control gallery are supplied with a protective netting, carefully earthed. Adjacent to the gable where the roentgen tube is placed, there is a well ventilated storage battery room.

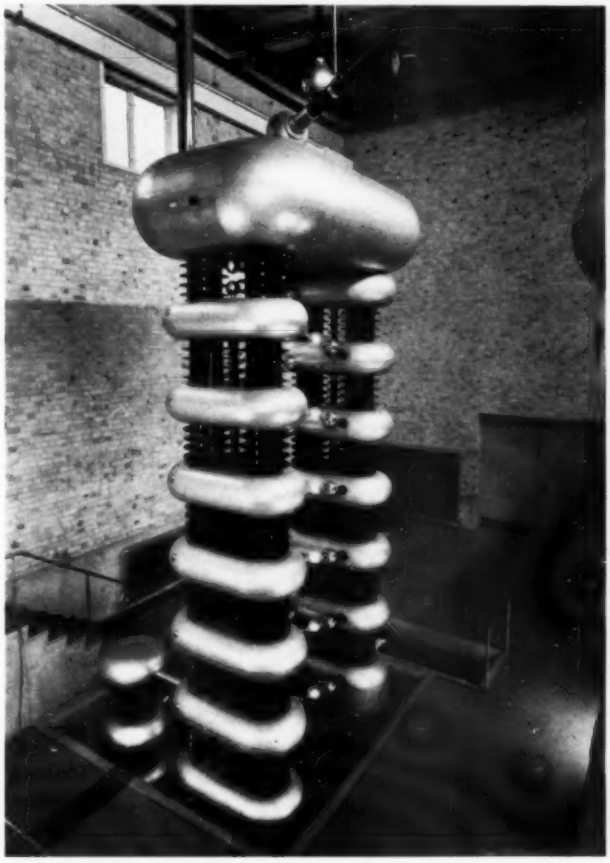

Fig. 3. The high voltage generator.

The High Voltage Generator

(See Fig. 3)

The COCKCROFT and WALTON generator[1] (A—A in fig. 2) is built in six stages, each of up to 200 kV. The filament currents for the rectifier valves are obtained from D. C. generators built in between the porcelain condensers and coupled with each other by axes of porcelain. They are driven by motors situated in the base. The number of revolutions of the axes is read on instruments in the control room. Besides this, the

[1] Designed by NORDELL, Sieverts Kabelverk.

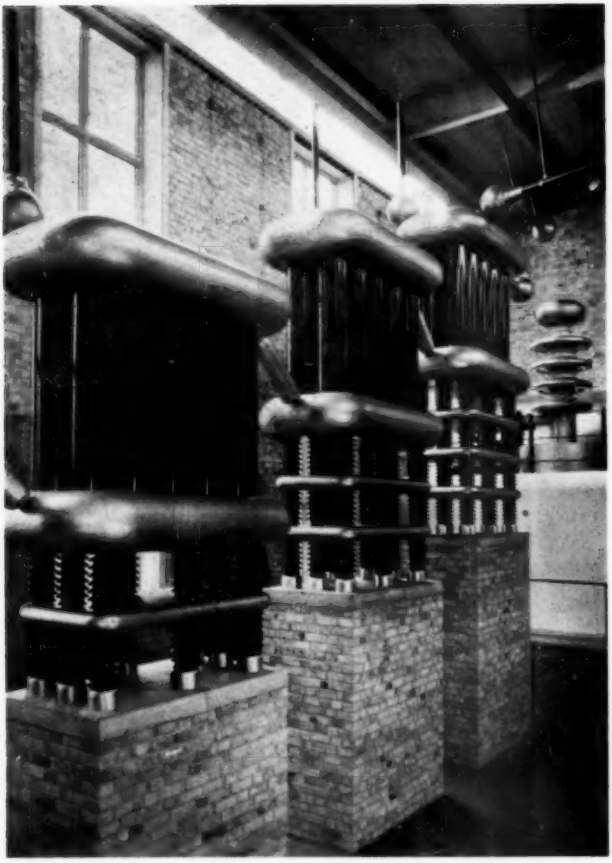

Fig. 4. The condenser battery with the roentgen tube and the irradiation room in the background.

filament heating voltage of each valve can be observed on instruments placed in the corona shields. The top condenser is supplied with a spark gap (3) to avoid excess voltages at rapid discharge. Between the upper terminal of the generator and the earth (the ceiling) there is a high voltage resistance (B—B in Fig. 2) consisting of 600 resistors of together 3,000 megohms in a bakelite tube. The voltage of the generator is obtained by measuring the current in the resistance, and as a control, also by means of an electrostatic voltmeter (4) connected to a small fraction of the resistors. By measuring the current with microammeters (5 and 6 having

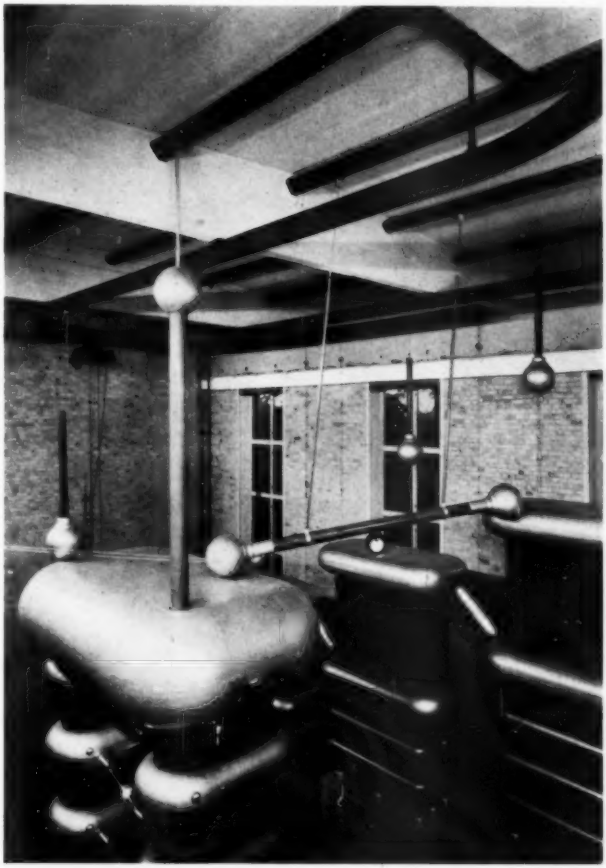

Fig. 5. Arrangement for high voltage connections and earthing.

measuring ranges corresponding to 90—300, 180—600 and 360—1,200 kV) at both ends of the resistance, correction may be made for the corona loss due to the resistors. The generator is run on stabilized 220 volts D. C.

The Condenser Battery

(See Figs. 4 and 5)

The condenser battery (C—C in Fig. 2) consists of 40 condensers, each of about 0.11 μF and for a maximal voltage of 250 kV. The condensers are arranged in 4 groups and placed so that the groups can be

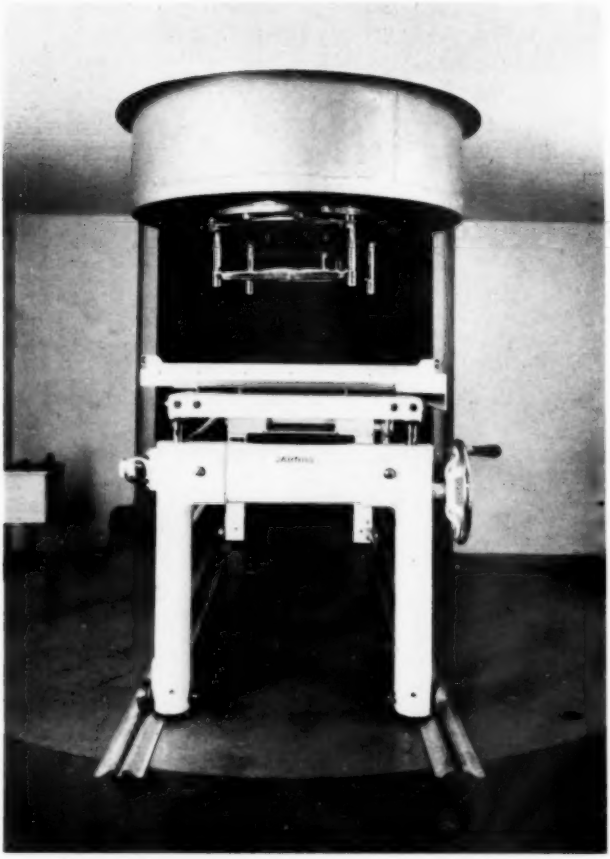

Fig. 6. Lower side of roentgen tube with holders for filters and diaphragms. Treatment table on elevation platform.

connected either in parallel with a capacity of 4.4 μF at 250 kV, or also 2×2 groups in a series parallel with 1.1 μF and 500 kV, or all groups in a series with a capacity of 0.27 μF at a maximum of 1,000 kV. One terminal of the condenser battery is earthed by a strong copper strip, and the other can be brought into contact with the roentgen tube by means of a connecting rod (8) driven by a motor. The high voltage generator, as well as the different groups of the condenser battery, can be earthed by means of motor driven spherical contacts hanging in bakelite tubes containing resistors (19, 20).

To charge the high voltage condenser battery it can be connected to the generator through a resistance of 50 megohm and a microammeter by means of a motor driven device.

The Roentgen Tube

(See Figs. 5 and 6)

The roentgen tube (D—D in Fig. 2) consists of a cylindric, water-cooled tank, with an interior diameter of about 100 cms., and an interior height of about 80 cm. This tank is fitted into the ceiling of the radiation room mentioned earlier, and at the bottom it has an opening covered by an iron lid, 500 mm. in diameter. The lid is removed when the anode and the cathode filaments are to be assembled. The lid is fitted with a diaphragm for the roentgen beam and a holder for auxiliary diaphragms. Upwards, the tank is continued by a cylindrical tube from which there are connections to two high vacuum units (9). These consist of two-stage Kinney pumps each with a capacity of 22 liter/sec and two oil diffusion pumps each with a capacity of 500 liter/sec.

Fig. 7.

The anode is insulated from the earth by four sets of insulators separated by corona shields, enabling also continuous operation at high voltages. The anode is fixed to the topmost corona shield by a vertical tube with a diameter of about 10 cm. Various targets may be attached to the lower end of this tube situated in the centre of the cylindrical tank. Along the cylindrical surface of the tank there are two copper rings with a diameter of ca. 85 cm. Between these rings wolfram heating filaments are stretched.

To measure the vacuum, Pirani gauges are inserted between the backing pumps and the oil diffusion pumps and at the roentgen tube. There are also 3 ionization vacuum gauges, two of which are placed between the oil diffusion pumps and the appropriate vacuum valves and one joined to the roentgen tube.

At present experiments are being made with two different types of anodes. One consists of sheet wolfram (Fig. 7) in the form of a cylinder, and is intended for irradiation of biological objects, or radiation measuring instruments sunk into the anode stem. They are cooled by means of a water jacket of which the temperature can be observed by means of an instrument built into the upper terminal of the tube. A motor driven drawbridge makes the upper part of the roentgen tube easy acces-

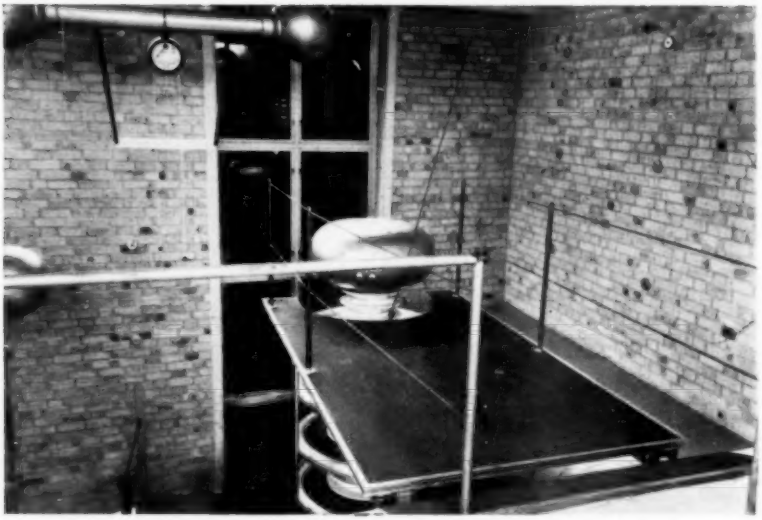

Fig. 8. Drawing bridge for bringing test objects into the target.

sible (See Fig. 8). The other anode is intended for experiments with concentrated roentgen radiation for therapeutic purposes. The appearance of this anode is shown in Fig. 9, which shows a copper anode for preliminary experiments. For higher dosage rates it is expected that an anode of tantalum will be used or an anode composed of wolfram plates. The principle of the method used is shown in Fig. 10.

A further improvement of the relative depth dose can be obtained with a radial diaphragm of the type shown in Fig. 10. Similar arrangements have earlier been suggested, *e. g.* by Bossi.[1] The reader is further referred to the next article in this issue.[2]

The cathode is composed of a great number (max. 144) of wolfram filaments in their present stage requiring a heating current of 2,000—3,000 amperes (electron emission up to 2,000 amperes) at a voltage of about 12 volts. This is obtained from two storage batteries of 16 volts which, when coupled in parallel, can give currents of up to 20,000 amperes. From the battery heavy copper leads pass to two motor driven switches capable of breaking a maximum of 10,000 amp. and through a water-cooled variable resistance with a maximum resistance of 0.005 ohm. This is made of a special steel alloy and consists of four iron tubes 2

[1] Bossi, R: Ricerca Scientifica 16 (5—6) p. 622, 1946.
[2] Lindell, Sievert, Wahlberg (Acta Radiol. 33, p. 344, 1950).

Fig. 9.

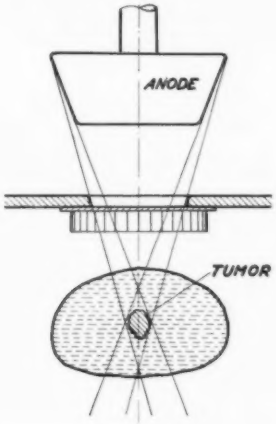

Fig. 10.

meters long and 42 mm in diameter and with a wall thickness of 3.25 mm. It can be varied by means of a remote control gearing motor which drives a moving contact containing strong copper-carbon brushes.

If the water-cooling should stop during the operation the resistor may be damaged after a few seconds. There is therefore a pressure tank with a pressure switch which, if the water-pressure decreases below a certain level, automatically disconnects the filament circuits by setting the motor driven switches in function. The temperature of the water from the cooling system is registered in the control room as well as the temperature of that coming from the roentgen tube.

In the filament circuit there is also a shunt that permits direct measurement of the current. The voltage between the heating wire holders is measured directly and for very accurate work by a compensator.

The arrangements in the filament circuit is seen in Fig. 12.

A special instrument (as shown in Fig. 13) has been constructed for measuring the duration of the roentgen radiation. A small compressed air turbine, commercially made for grinding machines, and allowing of speeds up to 60,000 r/min, has been rebuilt, so that a disk of photographic film can be fastened to its axis. This disk rotates with a speed corresponding to a peripheral velocity of more than 100 m/sec. By means of a gold diaphragm with a hole of about 0.1 mm. diameter, the roentgen radiation can be directly recorded on the film. The radiation time is determined by an ordinary cathode ray oscillograph and an audio frequency generator or by a specially constructed frequency meter. The apparatus allows observations down to a few microseconds.

Fig. 11. Filament heating regulators. In the background to the right the watercooled resistance, in the foreground the two motor driven switches.

A cathode ray oscillograph for very rapid registrations is also under construction, intended for observations of the discharge through the roentgen tube, in order to facilitate the prevention of high frequency disturbances of very high voltage, and also for observations on the discharge time.

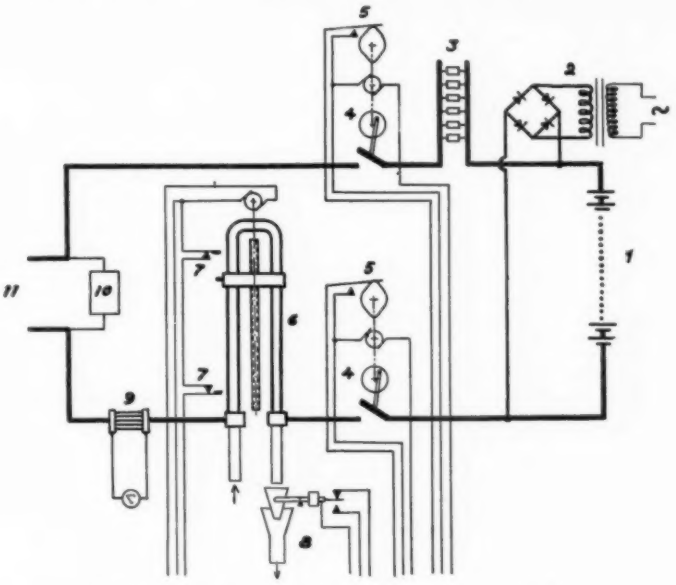

Fig. 12. Filament circuit for the roentgen tube.

1. Storage battery 16 V, max. 20,000 A.
2. Charging set.
3. Fuses 9 × 600 A.
4. Motor-controlled switches.
5. Contact arrangement preventing one switch closing the circuit before the other is in the position where a disconnection can be made immediately.
6. Water-cooled pipe resistors with motor controlled sliding contact.
7. Stop and signal contacts.
8. Electric contact on water pipe for signal and automatic breaking of the circuit if water fails.
9. Measuring shunt.
10. Compensator for accurate voltage control.
11. To filament of roentgen tube.

The Control Arrangements

(See Figs. 14 and 15)

All operating devices are installed in a control room in the previously mentioned gallery, from which a good view of the high voltage plant can be obtained. At the top of the instrument stand, to the left of fig. 14, the revolution counters and ammeters for the two driving motors for the filament current generators will be found, and also the devices connected

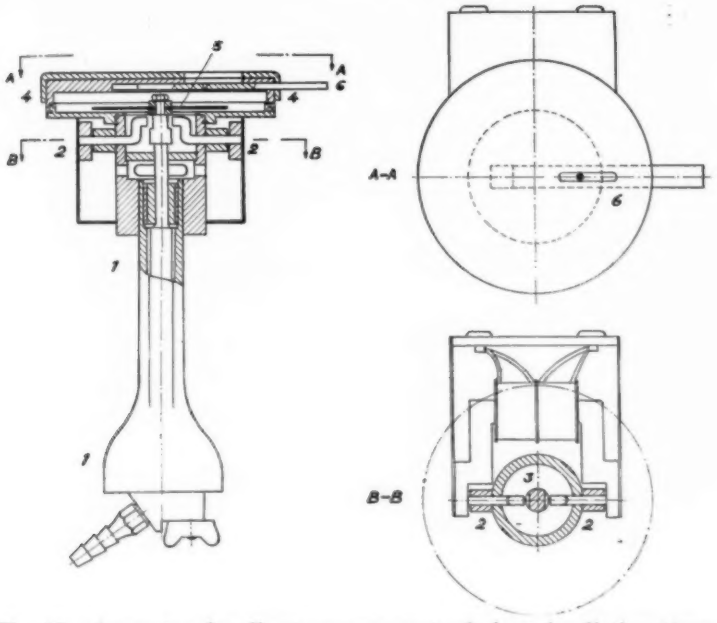

Fig. 13. Apparatus for direct measurement of short irradiation times.

1. Small compressed air turbine for max. 60,000 r. p. m.
2. Pole shoes of electromagnet with one feeding coil and one registration coil for connection to an oscillograph or frequency meter.
3. Flattened axis of steel.
4. Light-proof and radiation protected casing.
5. Rotating photographic film diam. 60—80 mm.
6. Movable gold diaphragm with hole diam. of 0,1 mm.

with their start and speed control. Next come the connecting devices for the charging of the filament storage battery, and the voltmeters for the relays (24 V storage battery) and for the stabilized and unstabilized 220 V a. c. The switching on of the circuit is blocked by key-locked switches. At the bottom of the instrument board fittings for lighting are fixed, *e. g.* search-lights for the instruments built in the corona shields and push buttons for the dark-room curtains.

In the opposite corner of the control room (see fig. 15) is an instrument stand for the earlier mentioned ionization and Pirani vacuum gauges, the control for the diffusion pumps, and also the temperature reading for the cooling water connected to the same, and the starting switches for the backing pumps. Between the two described instrument stands are the controls for the high tension voltage, the filament current

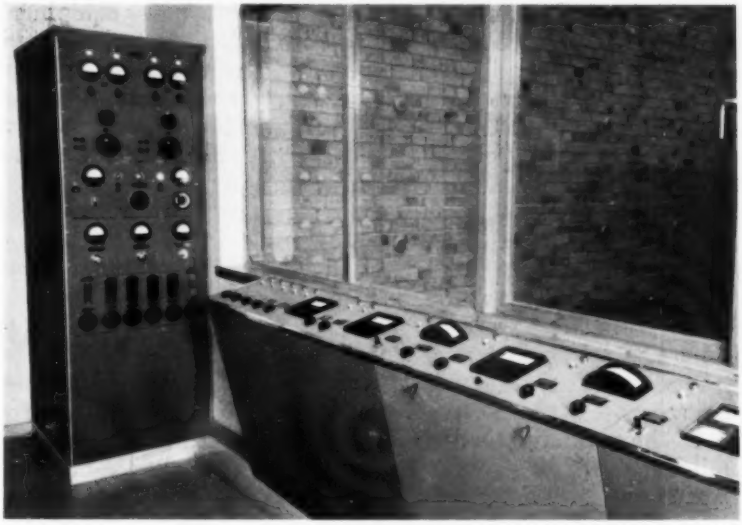

Fig. 14. The control room. Generator and high voltage control instruments.

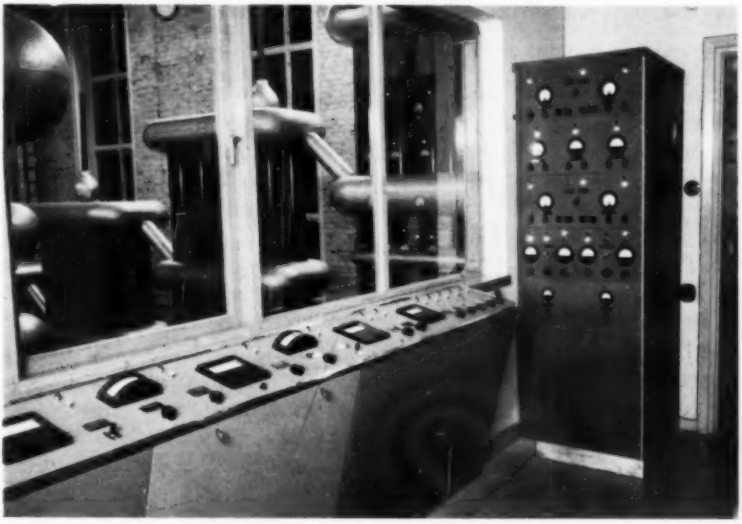

Fig. 15. The control room. Vacuum and filament control instruments.

for the roentgen tube, and also the requisite measuring equipment and switches for the remote-controlled earthing devices and the filament circuit breakers. To avoid accidents in routine work the high voltage cannot be connected unless both an optic and an acoustic signal of warning is energized. The latter comes into operation if the door to the high tension laboratory is opened. The high tension is blocked until the motor-operated earthing and connection rods are in their right positions. Before the high tension is switched on there will further automatically sound a short signal of a special type as a warning to those working in the irradiation room, or in other places in the laboratory that cannot be observed from the control room. These devices, besides the voltmeter and ammeter for the cascade generator transformers, are set to the left of the central control panel. To the right are the controls for the cooling water to the roentgen tube tank, and to the adjustable resistance in the filament circuit. There is besides, an instrument for the direct reading of the rotation speed of the previously mentioned rotating photographic recording device, and an ammeter for the reading of filament currents up to 10,000 amp. In the middle are instruments for reading the temperature of the cooling water from the roentgen tube and the filament resistor, and also the compensator, for determination of the filament voltage. The precision resistor boxes and the Weston cell for the compensator, are placed under the instruments and can be inspected through the opening out of the centre part under the switch board.

For the determination of the high-tension voltage the two above mentioned instruments are placed in the upper part of the cascade generator as is seen in fig. 3.

The entire equipment has been in operation for about one year and has proved satisfactory in all respects. The arrangements described allow very safe work and make it possible to concentrate further activity on the development of the roentgen tube and the testing of different cathode and anode constructions.

The building of the high voltage laboratory of the Institute of Radiophysics was financed by state grants and equipped with the help of grants from the Swedish Atomic Committee. The institute is also indebted to the Knut and Alice Wallenberg foundation for funds placed at its disposal for that part of the equipment concerned with deep roentgen ray therapy. The Sievert's kabelverk donated the condensers for the battery described above and Mr. Anders Dunder performed tasks far in excess of those stipulated by his contract.

I take this opportunity of expressing my sincere thanks to all those who have thus contributed to the completion of the new laboratory.

SUMMARY

A description is given of the new high voltage laboratory at the Institute of Radiophysics in Stockholm. The equipment is constructed for experiments with a roentgen tube designed for the following purposes: 1) the study of the biological action of intense irradiation of short duration. 2) the therapeutical application of such irradiation. In the latter case, use is made of arrangements which permit a concentration of the radiation on deep-lying tumours. The equipment consists of a COCKCROFT & WALTON cascade generator of 1.2 mill. volts, a condenser battery comprising 40 condensers each of 0.11 μF and a roentgen tube for the use of anodes with very large radiating surfaces. The electron emission in the roentgen tube is produced by means of a large number of wolfram filaments, which are fed with the current from a storage battery giving an effect of up to 200 kW. The emission current hitherto used has been of a magnitude of about 2,000 amperes.

ZUSAMMENFASSUNG

Die neue Hochspannungsanlage des Radiophysikalischen Institutes in Stockholm wird beschrieben. Die Anlage ist für Versuche mit einem Röntgenrohr konstruiert, das für zwei verschiedene Zwecke bestimmt ist: 1) Untersuchung der biologischen Wirkung kurzer, intensiver Bestrahlung, 2) Anwendung solcher Bestrahlung für therapeutische Zwecke mit Hilfe von Anordnungen, die eine Konzentration der Strahlung auf tiefliegende Tumore ermöglichen.

Die Ausrüstung besteht aus einem COCKCROFT & WALTON Kaskadengenerator von 1.2 mill. Volt, einer Kondensatorbatterie, die aus 40 Kondensatoren von je 0.11 μF zusammengesetzt ist, sowie einem Röntgenrohr, das zur Anwendung von Anoden mit sehr grosser Fokusfläche bestimmt ist. Die Elektronenemission im Röntgenrohr erhält man durch eine grosse Anzahl Wolframdrähte, welche von einer Akkumulatorbatterie gespeist werden, die einen Effekt von bis zu 200 kW abgeben kann. Der bisher verwendete maximale Emissionsstrom war 2,000 Ampere.

RÉSUMÉ

Dans cet article sont décrits les nouvelles installations à haute tension de l'Institut de Radiophysique. Ces installations ont été construites pour des essais avec un tube Roentgen destiné aux emplois suivants: 1) Recherches sur les effets biologiques d'une irradiation intense mais de courte durée. 2) Utilisation d'une irradiation de ce genre à des fins thérapeutiques, avec des dispositifs permettant de concentrer les rayons sur des tumeurs profondément situées. L'équipement est constitué par un générateur à cascade de 1.2 millions de volts, du type COCKCROFT et WALTON, une batterie de condensateurs composée de 40 condensateurs dont chacun a une capacité de 0.11 μF, et enfin un tube avec des anodes à très grande surface d'émission des rayons. L'émission des électrons à l'intérieur du tube se fait grâce à un grand nombre de fils de tungstène incandescents, qui sont alimentés par le courant d'une batterie d'accumulateurs pouvant atteindre un effet utile de 200 Kw. Jusqu'à maintenant on a employé des courants d'émission de l'ordre de grandeur de 2,000 ampères.

FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

A METHOD OF CONCENTRATING ROENTGEN RAYS FOR DEEP THERAPY[1]

(Preliminary reports)

by

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Introduction

In a preceding paper in this volume one of the authors[2] gives an account of the new high voltage laboratory at the Institute of Radiophysics of King Gustaf V's Jubilee Clinic, Stockholm, and of a new type of roentgen tube with a conical anode intended *i. a.* for attaining an extremely high relative depth dosage.

Here some additional information is given and also a few preliminary results of the investigations already performed.

As described in the paper quoted above, the apparatus consists of a roentgen ray tube, which can be connected to a condenser battery, charged to a high voltage by means of a cascade generator. The condenser battery is discharged through the tube, in which a large current is emitted from the filaments of the cathode. The discharge lasts only some 100 microseconds and the radiation is consequently of great dosage rate. The aim of future experiments is to construct a tube for a dosage distribution suitable for such therapeutic purposes where it is necessary to give a high dosage in the tumour without destroying too much of the surrounding normal tissues. In this connection we will make further investigations of the possibility of improved treatment conditions with the conical anode described in the paper just mentioned.

Because of the limited space in this volume we must leave to a later occasion the discussion of earlier methods described in the literature. However, we wish especially to draw attention to the works of MAYNE-

[1] Submitted for publication, Febr. 1, 1950.

[2] SIEVERT (Acta Radiol. vol. 33, p. 328, 1950).

ORD[1], GREEN et al.[2], and BOSSI[3,4]. The last author has worked on a somewhat similar principle to the one used in our investigation, but has employed the inside of a ring-shaped anode, which does not seem to allow the concentration effect which is the intention here.

Cathode Design and Construction

The hot cathode in this construction will give an electron emission reaching several thousand amperes. It consists of a number of filaments (at most 144) connected in parallel around the anode. The filaments are

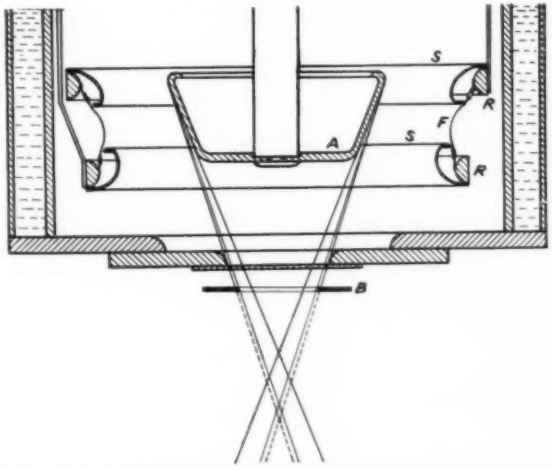

Fig. 1. Inside view of the tube showing the anode, surrounded by filaments.

pure wolfram wires, each 12.4 cm long and 0.05 cm in diameter. As shown in Fig. 1, they are mounted between two horizontal copper rings. In order to simplify their replacement they are attached to tab terminals. As nickel is the only metal easily weldable to wolfram and we want to avoid too much hot nickel being present in the evacuated volume, the wolfram wires have first been welded to molybdenum rods (0.3 cm in diameter) with a nickel foil. The molybdenum rods, which will not be damaged in the welded joint by the heating from the incandescent filaments, are sufficiently cool in their opposite ends to permit an ordinary weld to cable clips of some suitable material. Here nickel is convenient, being easy to weld to molybdenum. The nickel clips are

[1] MAYNEORD et al. (Brit. Journ. Rad. Vol. 22 (1949), p. 185).
[2] GREEN, JENNINGS a. BUSH (Acta Radiol. 31, p. 273, 1949).
[3] BOSSI (Ricerca Scientifica 16, 5—6 (1946), p. 622).
[4] BOSSI (Acta Pontificiae Academiae Scientiarum, Vol. 11 (1946), p. 117).

fixed to the copper rings by iron screws, which are bored through so that no gas can remain in the cavities after the tube is evacuated.

It is important that the terminals should not give rise to any random cold-emission discharge; for that reason they are screened by well rounded copper shields.

The large emission current is obtained by heating the filaments to a very high temperature. This is done at the cost of their average life, which is reduced to a few hours.

The cathode is fed with direct current from a storage battery, from which, during short periods, a current of up to 20,000 amperes can be drawn. The storage battery consists of two halves, each giving 16 volts, which can be connected in series or parallel. The filament power is between 15 and 60 kW, *i. e.* each single filament draws a current between 20 and 30 amperes.

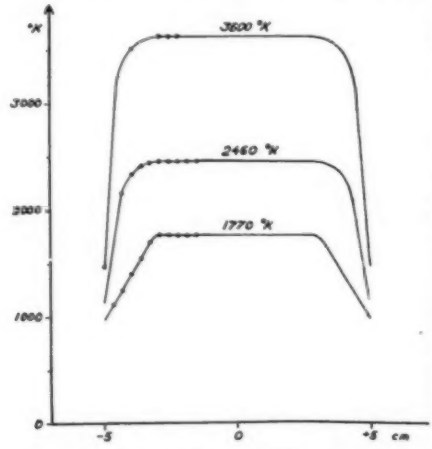

Fig. 2. Temperature distribution along a wolfram filament.

A compensator in the control room makes it possible to measure the filament voltage with great accuracy, this measurement being important for two reasons. First, the electron emission varies rapidly with the voltage, and secondly a small voltage increase will cause a considerably shorter average life as the filaments are used at very high temperatures. It should be observed that it is more expedient to measure the voltage than the current since the electric resistance of wolfram increases with temperature so rapidly that the relative current change will be only about half as large as the voltage change causing it.

In estimating the temperature and emission of the filaments, consideration must be taken of the conduction of heat through the terminals. If, considering radiation losses only, a certain voltage V can be calculated to give an equilibrium temperature T throughout the filament, it will not be necessary to have quite that voltage, but a lower one V_1 to get the same temperature at the middle of a filament that is cooled at the terminals.

Similarly the electron emission I_e that can be expected on the presumption that the whole filament has the temperature T, must be multiplied by a factor < 1 to find the emission from a filament cooled at the terminals and having the centre temperature T.

The voltage correction $V - V_1$ is about 0.3 to 0.4 volts. Fig. 2 shows the results from temperature measurement on a filament, giving the temperature variation along a wolfram wire, 10 cm long and 0.05 cm in diameter, welded between two 0.3 cm diameter molybdenum rods.

The incandescent filaments are very soft and may be deformed at full load by the magnetic forces caused by the currents. These forces can be estimated approximately if we assume that all the filaments are mounted straight and parallel around the anode.

Let n be the number of filaments, and I denote the total current through the cathode, where the filaments are mounted at the distance a cm from the centre of the tube, each filament being l cm in length. Then the force exerted on any single filament in the direction of the centre is:

$$F = \frac{\mu_0}{4\pi} \cdot \frac{l\, I^2}{na} \quad (n \gg 1).$$

This force acts upon each filament as long as all of them draw current. During the discharge another force will come into consideration, viz. the effect of the current to the target. We may form an idea of its magnitude by comparing it with half the force that will act upon the filaments if the emission current flows through a long conductor in the centre

$$F^1 = \frac{\mu_0}{4\pi} \cdot \frac{l \cdot I I_e}{na}$$

that is

$$F^1 = \frac{I_e}{I} F.$$

Large currents make the forces so considerable that it is dangerous to apply full voltage to the filaments at once, especially as the resistance of cold wolfram wires is only one twentieth of the resistance near the melting point.

Fig. 3 shows emission currents calculated for different filament voltages and diameters. In the same figure some curves showing the estimated average life are drawn.

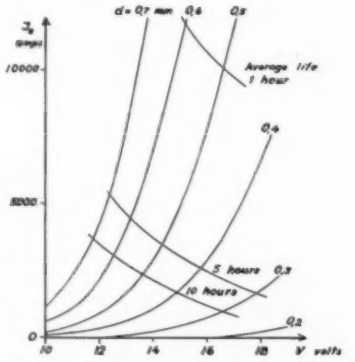

Fig. 3. Electron emission from 100 filaments as a function of diameter and voltage, with curves showing estimated average life.

The Load on the Anode Surface

In the choice between different anode materials we want to find a metal that in the best manner complies with the following conditions:

1. High atomic number.

2. High loading capacity, *i. e.* high maximum temperature (T_m) on the anode surface, high thermal conductivity (λ), specific heat (c) and density (ϱ).

3. Easy to work up to a truncated cone.

For small time values the temperature increase of a target surface that during the time t has been loaded with the effect P is:

$$\Delta T = \text{const} \cdot \frac{P}{A} \cdot \sqrt{\frac{t}{\lambda \varrho c}}$$

The energy transferred during the same time is $W = P \times t$, and thus

$$W = C_I \cdot A \cdot (T_2 - T_1) \cdot \sqrt{\lambda \varrho c} \cdot \sqrt{t} = C_{II} \cdot \sqrt{t}$$

If a condenser battery with the charge CV is discharged through the roentgen tube, in which the emission current I_e is to be dissipated, the following relations will apply

$$\begin{cases} W = \frac{1}{2} CV^2 \\ t = \dfrac{CV^2}{I_e} \end{cases}$$

The above relations combine to give an expression for the highest permissible voltage to the anode

$$V_{max} = \sqrt[3]{\frac{4 C_I^2 A^2 (T_m - T_0)^2 \cdot \lambda \varrho c}{C \cdot I_e}}.$$

With the value of $C = 0.277\ \mu F$ we get the following relation, applicable to the tube that has been used in our experiments

$$V_{max} = 180{,}000 \cdot \sqrt[3]{\frac{\lambda \varrho c \cdot A^2 \cdot (T_m - T_0)^2}{2{,}400 \cdot I_e}};$$

λ = thermal conductivity (cal/cm°s)
ϱ = density (kg/dm³)
c = specific heat (cal/°g)
T_m = highest permissible temperature (°C)
T_0 = initial temperature (°C)
I_e = electron emission (amperes)
A = surface area (cm² — in the experiments max. 2,400 cm²).

Fig. 4 shows the maximum permissible load with different target materials. Among those allowing high surface load it remains to select the very best with regard to atomic number and mechanical properties convenient for manufacturing the anode in question. Of the three best metals, viz. W, Ta and Mo, Mo has too low an atomic number. Of W and

Ta, between which the atomic number differs by only one unit, Ta is most easy to work.

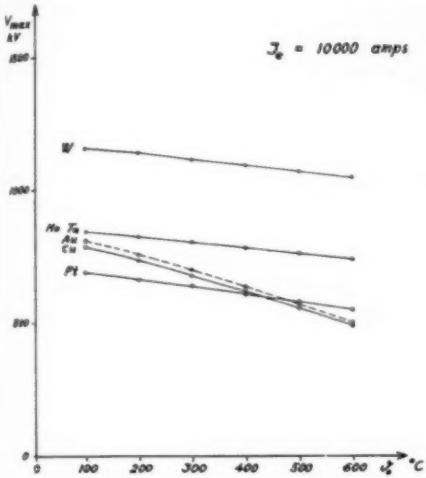

Fig. 4. Maximum permissible load on targets of different materials, calculated for a surface area of 24 dm² and an electron emission of 10,000 amperes.

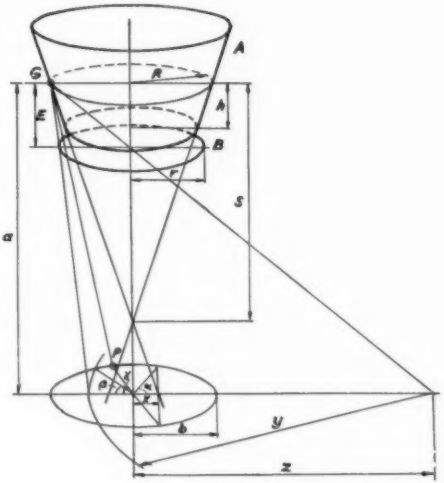

Fig. 5.

Calculation of the Radiation Dose Distribution

The purpose of the anode shape here described[1] is to give a roentgen ray distribution such that the radiation dose outside the treated volume is as small as possible in proportion to the dose within it.

In the sequel we shall try to picture the distribution of dose under a conical anode. Some simplifying assumptions will have to be made — the real dose distribution cannot be determined without practical measurements in each case.

In Fig. 5, A represents the conical anode, and B a circular hole diaphragm, concentric to the cone axis. The radiation intensity I will be studied in points at varying distances, a from the anode and b from its axis. To begin with we assume that the height of the anode can be neglected, and that the intensity is independent of the direction of radiation from the emitting surface. The calculation refers to the conditions in vacuum.

[1] See SIEVERT (Acta Radiol. Vol. 33, p. 328, 1950).

From Fig. 5 we have:

The radiation from the point G on the anode falls upon the fraction $\frac{\pi - \alpha - \beta}{\pi}$ of the circle periphery defined by the co-ordinates a and b.

The distance between a point P on the periphery (a, b) and the point G on the anode is

$$\overline{PG} = \sqrt{R^2 + b^2 - 2Rb\cos\gamma + a^2}\,.$$

For the radiation intensity we have the expression

$$I = \text{const.}\,\frac{1}{\pi}\int_{\beta}^{\pi-\alpha}\frac{d\gamma}{R^2 + b^2 - 2Rb\,\cos\gamma + a^2} =$$

$$= \text{const.}\,\frac{2}{\pi}\,\frac{1}{\sqrt{(a^2+b^2+R^2)^2 - 4R^2b^2}}\left|\operatorname{arc\,tg}\left[\sqrt{\frac{a^2+b^2+R^2+2Rb}{a^2+b^2+R^2-2Rb}}\cdot\operatorname{tg}\frac{\gamma}{2}\right]\right.,$$

or for simplicity's sake

$$I = C\cdot\frac{2}{\pi}\cdot\frac{1}{\sqrt{MN}}\left|\operatorname{arc\,tg}\left[\sqrt{\frac{N}{M}}\cdot\operatorname{tg}\frac{\gamma}{2}\right]\right.,$$

It remains to find expressions for the integration limits α and β,

$$\left.\begin{aligned}\cos\alpha &= \frac{x}{b}\\ x &= \frac{a-s}{s}\cdot R\end{aligned}\right\} \quad \because \cos\alpha = \frac{a-s}{s}\cdot\frac{R}{b}$$

$$\left.\begin{aligned}\cos\beta &= \frac{y^2 - z^2 - b^2}{2bz}\\ y &= r\cdot\frac{a}{E}\\ z &= R\cdot\frac{a-E}{E}\end{aligned}\right\} \quad \because \cos\beta = \frac{r^2\cdot\frac{a^2}{E^2} - R^2\cdot\frac{(a-E)^2}{E^2} - b^2}{2Rb\cdot\frac{a-E}{E}}$$

These limits give for the different domains I—V in Fig. 6

$$I_I = 0$$

$$I_{II} = C\cdot\frac{1}{\sqrt{MN}}$$

$$I_{III} = C \cdot \frac{2}{\pi} \cdot \frac{1}{\sqrt{MN}} \int_{0}^{\pi-\alpha} \operatorname{arc\,tg}\left(\sqrt{\frac{N}{M}} \cdot \operatorname{tg}\frac{\gamma}{2}\right)$$

$$I_{IV} = C \cdot \frac{2}{\pi} \cdot \frac{1}{\sqrt{MN}} \int_{\beta}^{\pi} \operatorname{arc\,tg}\left(\sqrt{\frac{N}{M}} \cdot \operatorname{tg}\frac{\gamma}{2}\right)$$

$$I_{V} = C \cdot \frac{2}{\pi} \cdot \frac{1}{\sqrt{MN}} \int_{\beta}^{\pi-\alpha} \operatorname{arc\,tg}\left(\sqrt{\frac{N}{M}} \cdot \operatorname{tg}\frac{\gamma}{2}\right).$$

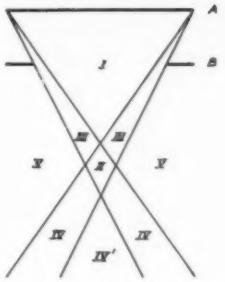

Fig. 6.

In these expressions the limits are obtained by substituting the angle γ. This is done most easily with help of the relation

$$\operatorname{tg}\frac{\gamma}{2} = \sqrt{\frac{1-\cos\gamma}{1+\cos\gamma}}$$

Within domain IV, $I = 0$ if $\beta \geqq \pi$, *i. e.* when $b \gtreqless \frac{R-r}{E} \cdot a - R$. Then $I'_{IV} = 0$.

Within domain V, $I = 0$ if $\beta \geqq \pi - \alpha$, *i. e.* when

$$b \geqq \sqrt{r^2 \cdot \frac{a^2}{E^2} + 2R^2 \frac{a-s}{s} \cdot \frac{a-E}{E} - R^2 \frac{(a-E)^2}{E^2}}.$$

In the relations above, the height of the anode has been neglected. The formulae are true only for circular elements, defined by the quantities R and s. A more exact expression can be obtained after integrating over the whole cone

$$I = \text{const.} \int_{0}^{h_{max}} \left(\frac{1}{\sqrt{MN}} \int_{\beta}^{\pi-\alpha} \operatorname{arc\,tg}\left(\sqrt{\frac{N}{M}} \cdot \operatorname{tg}\frac{\gamma}{2}\right)\right) dh.$$

In this expression M and N together with the limits $(\pi - \alpha)$ and β can be expressed as functions of the cone height h with the coordinates a and b as parameters. In the apex of the cone the slope of the iso-dosage surface can be deduced from the formula

$$\frac{a-s}{b} = -\frac{s}{R} \cdot \cos\left(\pi \cdot \frac{I}{I_{max}}\right)$$

I_{max} being the intensity in the apex.

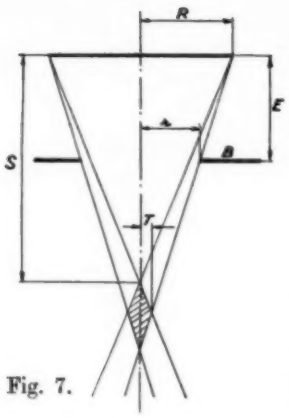

Fig. 7.

The radius (r) of the diaphragm (B) and its distance (E) from the anode are determined by the dimensions of the treated volume. This volume can be represented by its maximum horisontal radius T (See Fig. 7). Then the radius of the diaphragm is obtained from:

$$r = R - \frac{ER(R-T)}{S(R+T)}$$

The outside domain representing zero intensity, is moved closer to the treated volume as E increases. If a well-defined treated field is desired, a large value of the distance E should be chosen.

Experiments with the Roentgen tube

The experiments performed have been made with a tube provided with 48 filaments in the cathode, through which the heater current has been about 1,200 amperes at 12 volts. This current caused an appreciable displacement of the filaments towards each other in groups of eight.

The discharge time has been measured with help of a rotating film as described by SIEVERT in the quoted paper. The measured time, of the magnitude of 100 μs, indicates that about 50 % of the calculated electron emission will reach the target. The vacuum in the tube has been about 10^{-5} mm Hg.

A control of whether the discharge has been normal or not can be made by means of an apparatus consisting of a frame antenna, in which an e. m. f. is induced at each discharge. A ballistic instrument connected to the antenna via a crystal rectifier measures the e. m. f.

Through the antenna a magnetic flux, $\Phi = \text{const} \cdot I(t)$, flows, where I (t) denotes the current through the tube. If we neglect the inductance of the circuit, we obtain the following relation for the current in the ballistic instrument in series with the antenna

$$i = \text{const} \cdot \frac{d\Phi}{dt} = \text{const} \cdot \frac{dI(t)}{dt}$$

The instrument will give a deflection s, proportional to the electric charge passing through it during the discharge time τ:

$$s = \text{const} \int_0^{\tau} i \, dt = \text{const} \int_0^{\tau} \frac{dI(t)}{dt} \, dt = \text{const} \, (I_{\tau} - I_0)$$

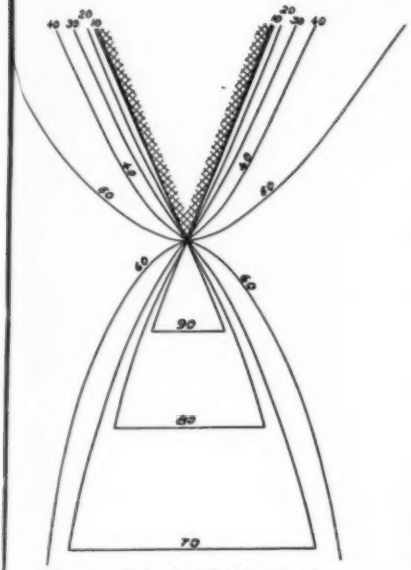

Fig. 8. Calculated distribution of dose without any diaphragm.

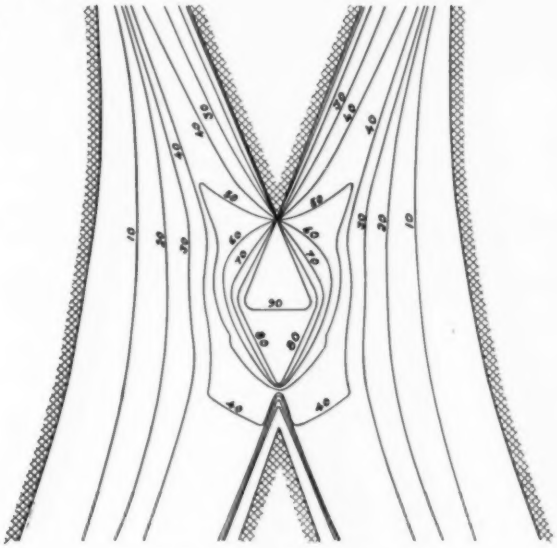

Fig. 9. Calculated distribution of dose with a diaphragm consisting of an absorber with a hole in the centre.

As there is a rectifier in the circuit, current will flow only as long as $\frac{dI}{dt} > 0$, *i. e.* the integration extends only to the moment when the current reachs its maximum value.

Thus:

$$s = \text{const.}\ (I_{max} - I_0) = \text{const.} \cdot I_{max}\,.$$

As long as the discharge is monotonous, the deflection on the instrument will be proportional to the maximum current. Great deflections indicate either that the current has been large or that the discharge has become oscillatory.

The experiments that have already been made with the conical anode have all been made at relatively low voltages with a copper anode and should be looked upon as quite preliminary. The purpose has been to find out how a reliable tube with a tantalum anode should be constructed.

The dimensions of the copper anode were:

Radius of upper terminal face: 25 cm
Radius of lower terminal face: 17 cm
Height: 20 cm.

Fig. 10 a.

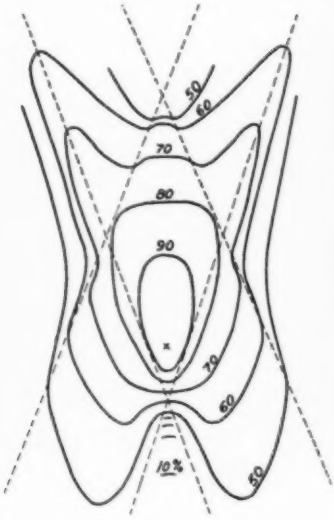

Fig. 10 b.

Fig. 10 a and b. Dose distribution in air under a copper anode.

Isodose curves, calculated as we have already described, are shown in Fig. 8 and Fig. 9. In the latter case a diaphragm was used.

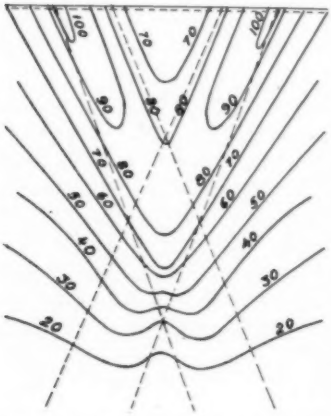

Fig. 11. Measured dose distribution in water at 250 kV.

As we have assumed that the radiation is emitted with the same intensity in all directions from the target surface, we have obtained the maximum dose in the apex of the cone. In reality, the intensity is reduced in directions forming small angles to the surface, because of the greater self-filtering of the target in these directions. As a matter of fact we find a dose maximum below the apex, as appears from Fig. 10 a, which shows a positive copy of a roentgen film that has been exposed vertically in air under the anode. Photometrical measurements on this film have given the isodose curves shown in Fig. 10 b.

It is of particular interest to know the

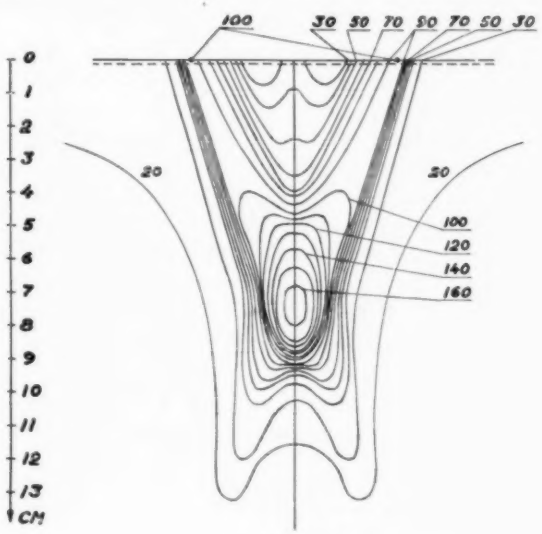

Fig. 12 a. Fig. 12 b.

Fig. 12 a and b. Dose distribution in a masonite phantom at 200 kV.

distribution of dose in a unit density material, because this knowledge will make it possible to estimate the depth dose in tissue. Measurements on radiation in water have given the results shown in Fig. 11. In consequence of the absorption the depth dose has here decreased compared with the dose in air, and is about 80 % of the surface dose. The peak voltage of the discharge through the tube at this exposure was 250 kV.

The distribution of dose can, however, be improved by means of a diaphragm arrangement consisting of lead plates, radially placed in vertical position under the anode. The arrangement is shown in Fig. 13.

The lead plates absorb radiation that has not been emitted in the direction of the treated volume near the apex of the cone. Thus the depth dose is improved, as shown in Fig. 12 a, which is a positive copy of a roentgen film exposed in a masonite phantom. Here the maximum depth dose

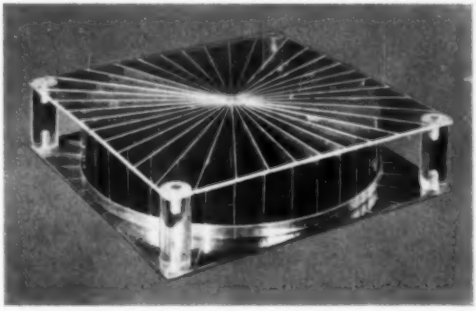

Fig. 13. Diaphragm arrangement.

is 160 % of the maximum dose on the surface, though the peak voltage of the discharge was only 200 kV (Fig. 12 b).

In all these experiments the doses have been very small. A tantalum anode will probably permit much higher voltages and consequently more energy on the condensers for discharge through the tube, better efficiency and less self-filtering in the tube. The efficiency will also be improved by the higher atomic number of tantalum. With 400 to 800 kW it seems possible to attain a dosage of 50 to 100 r at a depth of 10 cm and with a target—skin distance of 40 to 50 cm.

The authors are indebted to Knut and Alice Wallenberg's foundation, which, by awarding a grant, has enabled them to perform the investigations here described.

SUMMARY

Investigations have been made on the distribution of dose under a high-voltage roentgen tube with a conical anode according to SIEVERT. Some preliminary results are reported. Isodose curves have been calculated and are compared with results from dose measurements. A depth dose of 160 % has been obtained 8 cm from the surface in a masonite phantom at a discharge of 200 kV peak voltage. An electron emission of 1,200 amperes makes possible an irradiation time of only 100 microseconds.

ZUSAMMENFASSUNG

Untersuchungen über die Dosisverteilung unter einer Hochspannungsröntgenröhre mit einer konischen Anode von dem früher von SIEVERT beschriebenem Typ wurden durchgeführt. Einige preliminäre Resultate werden besprochen. Isodoskurven wurden berechnet und mit den Resultaten von Dosismessungen verglichen. In einer Tiefe von 8 cm unter der Oberfläche eines Masonitphantoms wurde eine Tiefendosis von 160 % bei einer Anfangsspannung von 200 kV erhalten. Die Elektronenemission von 1,200 Ampere ermöglicht eine Bestrahlungszeit von nur 100 Mikrosekunden.

RÉSUMÉ

Des recherches sur la répartition des doses avec une anode conique, du type précédemment décrit par SIEVERT, ont été exécutées en se servant d'un tube Roentgen pour tensions élevées. Compte-rendu de quelques résultats préliminaires. Les courbes d'isodoses ont été calculées et comparées aux résultats donnés par la dosimétrie. A une profondeur de 8 cm. sous la surface d'un fantôme de Masonite on a obtenu une dose profonde de 160 % avec une tension début de 200 K.V. Une emission d'électrons de 1,200 ampères rend possible une durée d'irradiation de seulement 100 microsecondes.

FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

A SURVEY OF ROENTGEN RAY ESTABLISHMENTS IN SWEDEN[1]

by

Lars-Eric Larsson

Ever since 1941, when the Radiation Protection Act came into force, all radiological work in Sweden has been supervised by the Institute of Radiophysics. The Institute exercises this control by inspecting at regular intervals all places where radiological work is done or radioactive substances are kept. When deemed necessary extra inspections are made, or condenser chambers for protection measurements may be sent out by post. The chambers are used in the radiological work during a given period as directed by the Institute and are then returned to the Institute to be read off.

All establishments supervised by the Institute are registered centrally under letters denoting their respective types. License-copies, inspection reports, correspondence, etc. are filed separately for each. Every plant is marked on a large map of Sweden by a flag bearing its current number. The letters denoting the different types of establishments are indicated by special colours or combinations of colours of the flags. In large towns each plant cannot be marked on the large map by a separate flag, and special town maps with individual flags are then provided.

New installations (about 200 every year), and establishments where changes have been introduced which according to the Act must be reported to the Medical Board (about 150 a year), are in addition shown on a separate map to enable the supervisors to include them in their inspection programs, which are planned with the aid of the principal map.

With the aid of the said register and files, the writer has computed the number of establishments doing radiological work which includes the use of roentgen rays, and drawn up an inventory of roentgen apparatuses in Sweden, all referring to conditions on December 31st, 1949.

[1] Submitted for publication, Febr. 1, 1950.

The roentgen establishments are differentiated as follows according to their purpose:

A. *Roentgen diagnostics, etc.*

Am) for Medical purposes
Av) » Veterinary »
Ao) » Odontological »
At) » Technical »
Au) Scientific and Educational purposes

B. *Roentgen treatment*

Bm) for Medical purposes
Bv) » Veterinary »
Bu) Scientific »

Wherever possible, the establishments in each sub-section have been divided according to categories, *e. g.*, in sub-section Am) into Hospitals, Cottage hospitals, Sanatoria for tuberculosis and TB clinics, Private and Others. The roentgen apparatuses are when possible also differentiated according to type — *e. g.* in sub-section Am) into condenser types, 6-valve (3-phase) types, 4-valve types and half-wave types. Apparatuses without valves or with only one valve are assigned to the last-named type. In some sub-sections it is also stated whether or not the apparatuses are provided with full high-tension protection. In sub-section Am) each type — except 6-valve apparatus — is in addition differentiated to show whether it is used as a fixed or transportable roentgen apparatus.

Table 1

Establishments and Apparatuses for Medical Roentgen Diagnostics

Type of establishment	Number of establishments	Type of apparatus							Total number of plants	Full high-tension protection	
		½-wave		4-valve		6-valve	Condenser				
		fixed	transportable	fixed	transportable		fixed	transportable		yes	no
Hospital: Roentg. dept.	137	56	162	176	8	68	4		474	461	13
» : No Roentg. dept.	50	45	6	5					56	54	2
Cottage Hospital	78	64	14	15	2				95	91	4
Sanatoria for tuberculosis and TB clinics	110	36	15	36		12	44	20	163	152	11
Private	418	412	5	7			3		427	403	24
Others	24	15	2	7			1		25	18	7
Total	817	628	204	246	10	80	52	20	1,240	1,179	61
		832		256			72				

In Table 1 the Hospital establishments are divided into two parts, »Roentgen Depts.» and »No Roentgen Depts.». Even if not organized as separate departments and accordingly not in the charge of specially

trained radiologists the main installation of each hospital is classed as »Roentgen Dept.», and so are all roentgen apparatuses in the hospitals which in the License issued by the Medical Board are managed by the chief of the main installation. The second group »No Roentgen Depts.» includes installations in for instance medical or orthopedic clinics managed by the head of the respective clinic. The reason why so many portable roentgen apparatuses are shown in the »Roentgen Dept.» group is not only that they are needed for work in the wards, but also that in Sweden the radiological work in operating theatres is nearly always done by the Roentgen staff of the hospital, and that accordingly the head of the main roentgen installation is also responsible for the apparatus used in the operating theatre. The group »Others» includes installations in military hospitals and municipal nursing institutions which cannot be referred to any other group.

Only 5 % of all the roentgen apparatuses in group Am) are not provided with full high-tension protection.

Sub-section Av), for Veterinary purposes, comprises 18 establishments with 20 roentgen apparatuses, of which 17 are $^1/_2$-wave, 3 are 4-valve. One of the 4-valves apparatuses is also used for roentgen treatment and then functions as a constant voltage apparatus. They are all provided with full high-tension protection. Most of these installations are located in the veterinary military hospitals.

Table 2

Establishments and Apparatuses for Odontological Roentgen Diagnostics

Type of establishment	Number of establishments	Roentgen apparatuses	Full high-tension protection	
			Yes	No
Private	1,606	1,620	1,312	308
Public Dental Service	348	350	344	6
In hospitals, but not available for Public Dental Service	14	14	14	—
Others	117	154	151	3
Total	2,085	2,138	1,821	317

The two Dental Colleges, the Municipal dental clinics for school children, and the Military dental clinics, are included in »Others» in Table 2. 15 % of the total number of dental Roentgen apparatuses are not provided with full high-tension protection, while the corresponding figure for private dental apparatuses is 19 %.

Table 3

Establishments and Apparatuses for Technical Purposes

Type of establishment	Number of establishments	Apparatus for Diffraction analyses	Apparatus for Fluoroscopy and Radiography, max. voltage, in kV					Total Number of apparatuses
			< 100	> 100 ≤ 150	> 150 ≤ 200	> 200 ≤ 250	> 250 ≤ 300	
Technical	55	15	24	26	3	5	3	76
Firms and shops selling roentgen apparatuses	9							
Total	64	15	24	26	3	5	3	76

It is here of no interest to register the number of apparatuses held by »Firms and Shops». These establishments serve no particular roentgen purpose, but are nevertheless accounted for in sub-section At).

The roentgen apparatuses for fluoroscopy and radiography are all $^1/_2$-wave and provided with full high-tension protection. They are grouped according to their max. voltages. Roentgen apparatuses for technical purposes are not restricted to the metal industry, but are also used in *e. g.* the provision and confectionery trades for continuous production control.

Table 4

Establishments and Apparatuses for Scientific and Educational Purposes

Type of establishment	Number of establishments	App. for Diffraction analyses	Spectrographs	Other Roentgen app.	High voltage installations for nuclear research	Total
Scientific Instit.	35	19	11	29	4	63
Schools	170			172		172
Private	3	1	1	4		6
Total	208	20	12	205	4	241

The Universities and Colleges establishments are included in the »Scientific Institutions» although their apparatuses are partly used for educational purposes. Group Au) does not include the installations at the Dental colleges, which are assigned to Group Ao), nor those at hospitals where medical students are trained, which belong to group Am). At school installations are generally specially designed for educational purposes, with a working voltage of less than 30 kV and a tube current much below 1 mA. The roentgen tubes are energized by means of in-

duction coils or electrostatic generators. Sometimes, however, old medical or odontological apparatuses when no longer able to serve their original purpose have been presented to or purchased by the schools. About 13 % of the total number of school-apparatuses are of this larger type.

The column »High voltage installations for nuclear research» includes the particle accelerators which are not exclusively intended for generating Roentgen radiation.

Table 5

Establishments and Apparatuses for Roentgen Therapy

Type of establishment	Number of establishments	Apparatus for deep therapy	Apparatus for contact therapy	Total Number of apparatuses
Hospital	66	111	22	133
Vet. hospital	1	included in group Av		
Scientific Instit.	1	1		1
Total	68	112	22	134

For more detailed information on roentgen therapy installations and apparatuses see THORÆUS' article in this issue (page 253).

All roentgen establishments and apparatuses are summarized in Table 6 below.

Table 6

A Summary by Sub-sections of Establishments and Apparatuses

Sub-section	Am	Ao	Av	At	Au	Total A	Bm	Bv	Bu	Total B	Total Number
Number of establishments	817	2,085	18	64	208	3,192	66	1	1	68	3.260
Number of Rtg.app.	1.240	2.138	20	76	241	3.715	133	— [1]	1	134	3,849

[1] Included in group Av.

In the sub-section »Odontological Roentgen Diagnostics» the numbers of photographic exposures made by each dentist a) in private establishments and b) in the Public Dental Service have been computed. The investigation have been made from information received when inspecting establishments, where radiological work was being done. It comprises 1,607 dentists in private practice and 488 dentists in the District Dental Policlinics. The results are shown in Table 7 and a diagram.

Table 7

Number of exposures per Dentist in Private Practice and in District Dental Policlinics

		Weekly Number of Photographic Exposures						
		<5	$>5 \leq 10$	$>10 \leq 15$	$>15 \leq 20$	$>20 \leq 25$	$>25 \leq 30$	>30
Dentists in private practice	Number	285	397	345	232	104	161	83
	in %	[illegible]	[illegible]	21.5	14	6.5	10	5
Dentists in the District Dental Policlinics	Number	115	[illegible]	130	51	6	7	18
	in %	23.5	33	26.5	10.5	1	1.5	4

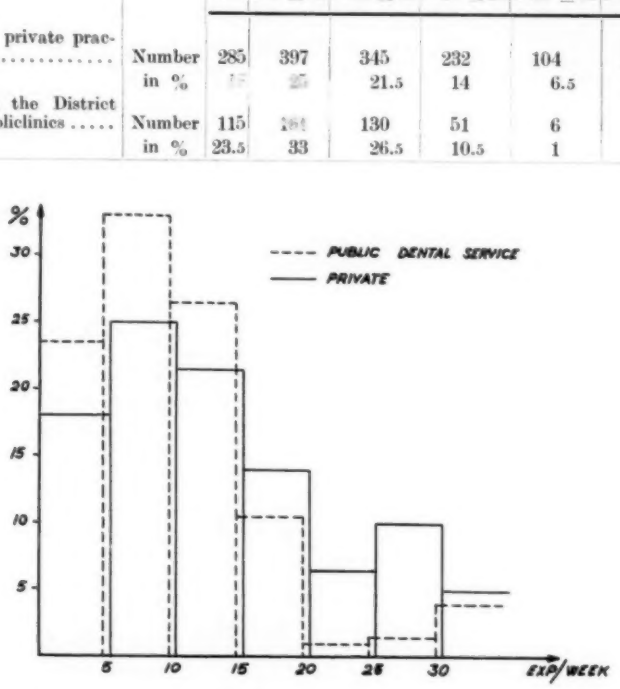

Diagram comparing the number of weekly exposures in Private Practice and in the Public Dental Service.

According to the Reports on the inspections of private installations for medical roentgen diagnostics, 41 % of them are used only for fluoroscopy, 13 % only for photographic exposures, and 46 % for both these purposes. The reports covered 396 establishments.

All the Diagnostic etc. roentgen installations are supervised by *one* of the three control sections of the Institute of Radiophysics — Control Section A. Since the Radiation Protection Act came into force on 1 July, 1941, more than 7,000 inspections of roentgen installations have been made by this section. For the last three years it has made between 1,000 and 1,200 inspections a year.

Finally it will be mentioned, that 60 % of the establishments for medical diagnostics purposes are of the types »Cottage Hospital, Private and Others». The volume of work carried out by such roentgen establishments is not very great and for that reason, because of economic factors one cannot direct complete radiation protection as in the roentgen departments of the hospitals. So their licenses include a special limitation to their roentgen work; *e. g.* permission only for a fixed number of exposures per week and a fixed time per week for fluoroscopy. Very often it can be difficult for the supervisor to decide how much roentgen work may be done having regard to the protection present in such establishments without any risks for the personnel.

In establishments where there is not full radiation protection it is necessary to carry out the roentgen work with the greatest care and for that reason the personnel receives detailed instructions as to how they should use the protection available.

These problems are also found in the odontological roentgen diagnostics, but there they are a little easier, because this part of the diagnostics is so special and includes only exposures of a few types.

Concerning the inspection procedure and the various investigations performed during the inspections the reader is referred to a paper by SIEVERT in this issue (page 191).

SUMMARY

The author gives in this paper an inventory of the Swedish establishments and apparatuses for roentgen work.

ZUSAMMENFASSUNG

In dieser Arbeit gibt Verf. eine Übersicht der Anlagen und Apparate für Röntgenarbeit in Schweden.

RÉSUMÉ

Dans cet article l'auteur fait un inventaire des établissements et appareils radiologiques en Suède.

FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

PROPOSALS FOR THE ESTABLISHMENT OF SWEDISH REGULATIONS ON ROENTGEN RAY PROTECTION[1]

made at the request of the Institute of Radiophysics

by

Thor Wahlberg

Since about ten years ago all radiological work in Sweden has been supervised by the Institute of Radiophysics. Through regular inspections and otherwise the Institute strives to obtain the best possible radiation protection conditions in the various radiological establishments. The regulations and instructions necessary from the point of view of protection are issued in *each individual case*. Although this procedure has generally proved to be very satisfactory there has arisen an increasing need for the drawing up of regulations on protection from radiation that have a *general application*. At an earlier date proposals had been worked out at the Institute for such regulations, but in the light of increased practical experience gained from supervisory work these proposals were found to be unsuitable in some respects.

The general regulations, the draft proposals for which are presented here, have to a large extent been adapted to practical situations which have arisen during a large number of inspections (over 8,000 between 1941 and 1949), and are in the main based on the following principles.

In accordance with what has often been the practice abroad the basis for the regulations is the radiation dose to which persons may be exposed without, according to our present experience, any obvious risks of injurious radiation effects arising. Investigations including that of HELDE (Acta Radiol., Vol. XXVII, p. 308—315, 1946) on the connection between blood changes and radiation risks support the view that there are good reasons for assuming that blood changes may appear through irradiation over long periods at very low daily doses. HELDE's investigation was made possible by the comprehensive supervisory work of the

[1] Submitted for publication, Febr. 1, 1951.

Institute and by the fact that persons engaged in radiological work are legally obliged to provide the Institute annually with information regarding, among other things, their blood count. Abnormal changes in the blood count may appear, at least in some people, even when doses of between 0.1 and 0.5 r per week are given over long periods. 0.1 r per week has been chosen as the »safety dose».[1] The choice of this low dose may be deemed justifiable since this »safety dose» must be presumed to apply, for example, to persons who are exposed to radiation because their home or place of work happens to be situated in the neighbourhood of a roentgen establishment. Such people as a rule, of course, could not be submitted to any special health inspections. On the other hand somewhat larger radiation doses might when necessary be permitted for persons who are submitted to regular health inspections. According to the Institute's experience there is no difficulty in avoiding radiation of more than 0.1 r per week for the personnel in the great majority of roentgen establishments. This fact has played an important part in the establishing of the above-mentioned »safety dose». This safety dose is primarily based on blood count investigations. It is, however, considered that it should not only apply to irradiation of the whole body but also of parts of it, as, for the sake of safety it should be assumed that irradiation which may give rise to blood changes may also cause still unproved changes, as yet unknown, in some tissue of special significance for the function of the body. Regarding peripheral parts of the body such as the hands and forearms, larger doses must, however, be permitted for practical reasons. This may even be warrantable from the medical point of view. With regard to patients who undergo radiological examinations or treatment only those regulations, of course, which discourage obviously unnecessary irradiation need to be considered. In this connection special attention should be directed to the necessity of avoiding irradiation of the sex glands in so far as this is possible. Further, special care must be taken in irradiation of children and pregnant women. Special demands respecting protection of the sex glands of the radiological personnel have not been found justifiable because, up to the present, no definite proof at all has been brought forward that the low safety dose chosen for irradiation of the body as a whole involves any genetic effects.

Regulations on protection from radiation refer firstly, to the arrange-

[1] Irradiation conditions at the different roentgen installations vary a great deal. In a number of cases irradiation takes place almost continuously during the whole of the working day: in other cases irradiation is divided up into a small number of exposures. Because of this, and of the fact that we have no satisfactory grounds for believing that (the dose being kept constant) the radiation effects definitely are dependent on the dosage rate, we have considered that the safety dose only should be considered as the radiation dose per week in the general regulations.

ment of safety appliances and secondly, to working technique. With regard to arrangements of safety appliances, no fundamental objections generally arise to applying a strict maximum permissible dose as a basis. On the other hand great practical and legal difficulties are involved in prescribing direct prohibitions against persons occupied with radiological work being exposed to radiation in excess of a certain dose. This is at any rate the case so long as the radiation intensity to which each person is exposed cannot be determined continuously and in detail. For this reason, instead of regulations on the maximum permissible irradiation, it is only prescribed that the best possible security against injurious radiation effects shall be aimed at. The lack of definite regulations on dosage for radiological personnel should not involve any serious difficulties as, when necessary, special supplementary regulations may be given in connection with the inspections of the Institute of Radiophysics and the dose measurements taken on these and other occasions.

The arrangement of safety appliances in a particular case should be so adapted that, even in the most unfavourable circumstances in that case, the safety dose is not exceeded. Certain protective devices such as tube housing, mobile protective screens, lead glass of fluorescent screens etc. which are produced in standard models, should, however, be adapted to the most unfavourable circumstances prevailing in the type of establishment in question. With regard to establishments for technical roentgen work, where the working conditions are very varied, the regulations are, to a larger extent, adapted to the situation which in fact occurs in each particular case, and rules are then made that the dose outside the protective screens may not exceed 0.1 r per week.

It was considered that the regulations should be given in a general, relatively brief form where only the more fundamental demands for radiation protection would be stated. Detailed information on the protective qualities of various materials, radiation output in different circumstances etc. and other advice and instructions on protection from radiation that may be called for have been separated from the main regulations. The advantage of this method is that future experience in the field of radiation protection may be put to better use in this »advice and instructions» which is more easily changed or supplemented than established regulations.

Exemption from the regulations is granted or may be granted in certain cases. By this means provision is made that organized roentgen work in medical practice or other spheres of activity is not put to serious disadvantage unnecessarily or without strong reasons. For instance a general exemption from the regulations is granted when strictly necessary in the best interest of the patient.

Although it was of course desirable that the regulations should in-

clude all radiological work it was considered desirable for the time being to issue general regulations for roentgen work only. This was because the practical experience of protection from radiation, and the biological effects of weak but repeated radiation which the Institute has gained through its supervisory work, has been predominantly connected with roentgen establishments. Moreover, for the present the postulates are lacking for making rules based on a common and practically applicable dose conception for all ionizing radiations.

The following are the proposals for the regulations.

General Regulations

1 §.

»Roentgen work» and »roentgen establishment» in these regulations mean every activity, respectively every establishment, in which roentgen-rays are generated at a voltage exceeding 5,000 volts.

2 §.

For everybody who is exposed to roentgen radiation, the best possible security against injurious radiation effects shall be aimed at.

Regarding persons who are exposed to roentgen radiation without being subject to roentgen examinations or treatments, satisfactory security against injurious radiation effects is postulated for anyone who is not exposed to a larger average dose than 0.1 r per week. This dose value refers to irradiation of the whole as well as of a part of the body. Regarding the peripheral parts of extremities satisfactory security is postulated if the average radiation dose does not exceed 1 r per week.

3 §.

Within premises around, above or below the locality of roentgen work the radiation dose shall not exceed 0.1 r per week if persons are present in these premises other than fortuitously while roentgen work is in progress.

4 §.

If entrance to the room for roentgen work or to areas within which the radiation dose might exceed 5 r per week is not effectively prevented during roentgen work, the roentgen establishment shall be so disposed that it is possible to observe from the control room if anybody enters the roentgen room or the above-mentioned areas.

5 §.

In establishments for roentgen diagnostics or therapy it shall be possible to observe the work or treatment place from the associated control unit.

6 §.

In locations used as a routine by persons taking part in roentgen work, or persons who are present during such work protective screens shall if possible be installed so that the dose does not exceed 0.1 r per week.

7 §.

Roentgen establishments shall be equipped with measuring instruments or other arrangements whereby the running conditions can be controlled with the necessary accuracy.

Such arrangements may, however, be omitted in roentgen establishments which are not used for roentgen therapy and where free regulation of the voltage and current is not possible if, at the control unit, clear information is posted up on the running conditions with different settings of the control.

8 §.

Premises in which roentgen work is carried out on a large scale shall be spacious and dry and equipped with good ventilation arrangements. Unless it causes great inconvenience this shall also apply to other rooms in a roentgen department.

9 §.

The head of roentgen-ray work shall see that the relevant regulations and instructions are observed and that available shields and devices important from the view-point of protection are used adequately.

10 §.

Workers shall use the protective apparatus provided, follow carefully these regulations or what is prescribed on the authority of the Radiation Protection Act, and otherwise contribute all that lies in their power toward the prevention of disease or accidents at work.

11 §.

The supplier of roentgen apparatus or of accessories essential thereto from the point of view of radiation protection shall see that the apparatus and accessories conform with these regulations.

The supplier of radiation protection material shall see that the material is furnished with information showing its protective properties in relation to the quality of radiation occurring in the purpose intended.

12 §.

In examination or treatment of a patient the regulations communicated here may be set aside in exceptional cases when strictly necessary in the best interests of the patient.

13 §.

For individual establishments or groups of establishments the Medical Board may make stricter regulations or permit such moderation of these regulations as appears justified in relation to special circumstances.

14 §.

In addition to the above general regulations the following special regulations shall apply to establishments for medical, odontological and veterinary roentgen diagnostics, establishments for roentgen therapy and roentgen establishments for technical purposes, for teaching and scientific purposes.

Special regulations relating to establishments for medical, odontological and veterinary roentgen diagnostics

15 §.

Roentgen tubes and housing shall together afford radiation protection in all directions except that taken by the beam used in the work in question (the useful beam). If the useful beam is completely screened off this protection shall, at a focal distance of two meters and at the maximum tube voltage used reduce the dose to, not more than 0.5 micro-roentgen when one mAsec is passed through the tube.

16 §.

The useful beam must not exceed what is necessary for the adequate performance of the work.

Primary diaphragms shall have at least the same radiation protective power as prescribed in 15 § for roentgen tubes and housing.

17 §.

The total filtration of the useful beam between the focus of the tube and the patient shall correspond to at least the values given below:

up to 60 kV 0.5 mm aluminium
above 60 kV 0.7 » »

18 §.

Rooms for roentgen diagnostics, in which the total of the roentgen work exceeds 50,000 mAsec per week and the direction of the radiation is not strictly fixed in relation to the shield required according to 3 §, shall be completely screened off from such adjacent premises where persons are present otherwise than fortuitously. The protective shields for this purpose shall, at the maximum tube voltage used, reduce the dose in the useful beam at a focal distance of two meters to not more than 0.5 micro-roentgen when one mAsec is passed through the tube.

19 §.

Fluorescent screens used in fluoroscopy shall be equipped with a shield which, with the highest tube voltage used in the work and at a focal distance of two meters, reduces the radiation in the useful beam to not more than 0.5 micro-roentgen when one mAsec is passed through the tube. The useful beam shall be so delimited that it does not fall outside the shield.

Under the fluoroscopy screen, or, when the screen is placed horizontally to that side of it facing the investigator, there shall be another shield with a radiation-proof connection to the screen's radiation shield. This second shield shall reduce the radiation dose to not more than 25 micro-roentgen in the conditions given in the preceding section concerning the protective shield of the screen. This second shield shall have a minimum width equalling that of the screen but not, however, less than 30 cm, and a minimum height of 40 cm. At a table used for screening recumbent patients, the width of the second shield shall not be less than 40 cm.

At a work place where the amount of fluoroscopic screening involves more than 50,000 mAsec per week the investigator shall as far as possible be completely protected against scattered radiation from objects in the useful beam by a shield with protective properties in accordance with the foregoing section.

Work places for fluoroscopy shall be equipped with arrangements by which the tube can be connected and disconnected from where the investigator is stationed.

The control arrangements which in fluoroscopy are operated by the investigator shall insofar as is possible be placed behind the shields described in this paragraph.

20 §.

In roentgen ray diagnostic work a larger radiation quantity than is needed for adequately carrying out the work shall not be used. In roentgen examination of persons under or of reproductive age special care shall be taken to avoid irradiation of the sex glands as far as possible. Special care shall also be taken concerning children and pregnant women.

Special regulations concerning establishments for roentgen therapy

21 §.

Roentgen tubes and housing shall together have a shield affording radiation protection in all directions except that taken by the beam used in the work (the useful beam). If the useful beam is completely screened off this shield shall at a focal distance of two meters and at the

highest tube voltage used, reduce the dose to not more than one micro-roentgen when one mAsec is passed through the tube.

With contact therapy apparatus the total shield in roentgen tubes and housing shall, when the useful beam is completely screened off, reduce the dose at 10 cm focal distance to not more than one micro-roentgen at the highest tube voltage used, when one mAsec is passed through the tube.

22 §.

Primary diaphragms shall have at least the same protective power as prescribed in 21 § for roentgen tubes and housing.

23 §.

In an apparatus which is not specially designed for contact therapy the housing shall be equipped with a shutter with a protective power corresponding to at least what is prescribed in the first section of 21 § for roentgen tubes and housing by which the useful beam can be effectively screened off. It shall be possible to operate the shutter from the control unit. There shall be signal arrangements visible from the control unit which show if the shutter is open or closed.

24 §.

Apparatuses as mentioned in 23 § shall be equipped with arrangements which effectively prevent unintentional irradiation without an additional filter and which make it possible to determine from the control unit which filter is in place and which treatment time card shall be used.

25 §.

Rooms for roentgen therapy, in which the direction of the radiation is not strictly fixed in relation to the shield required according to 3 §, shall be completely screened off from adjacent premises where persons are present other than fortuitously. The protective shields for this purpose shall, at the highest tube voltage used, reduce the dose in the useful beam at a focal distance of two meters to not more than 0.1 micro-roentgen when one mAsec is passed through the tube.

26 §.

The dose received at the control unit shall not exceed 0.1 r per week.

27 §.

In roentgen therapy unintentional irradiation shall be prevented as far as possible. With regard to persons under or of reproductive age special care shall be taken to avoid irradiation of the sex glands as far as possible. Special care shall also be taken concerning children and pregnant women.

Special regulations concerning roentgen establishments for technica purposes

28 §.

Roentgen tubes and housing shall together have a shield affording radiation protection in all directions except that taken by the beam used in the work in question (the useful beam). If the useful beam is completely screened off, the shield shall, at a focal distance of two meters and at the highest tube voltage used, reduce the dose to not more than 0.5 micro-roentgen, when one mAsec is passed through the tube.

29 §.

In a roentgen tube with several radiation windows, those windows which are not in use shall, during operation, be completely covered by a protective shield at least as effective as that prescribed in 28 § concerning roentgen tubes and housing.

30 §.

Exemption from the regulations in 28 § and 29 § is granted for establishments where the roentgen tube is surrounded in all directions by protective screens which in the prevailing scope of the work and running conditions reduce the dose to not more than 0.1 r per week and where entry to the area within the screens is effectively prevented.

31 §.

Rooms for technical roentgen work shall be screened off from premises where persons are present other than fortuitously. The protective shields for this purpose shall reduce the dose everywhere in the premises outside the room to not more than, 0.1 r per week in the operational conditions prevailing.

32 §.

At the control unit and at the observation place used in fluoroscopy the dose received shall not exceed 0.1 r per week.

Special regulations concerning roentgen establishments for teaching and scientific purposes

33 §.

The relevant passages of the preceding regulations relating to roentgen establishments for diagnostics, therapy or technical purposes shall also apply to roentgen establishments for teaching and scientific purposes.

34 §.

In small roentgen apparatuses such as ion tubes driven by small electrostatic machines or induction coils, which apparatus is used in practical demonstrations or other work in connection with teaching, special protections may be omitted if the electrical energy passing through the roentgen tube is less than 25 watt-hours per annum, and if one and the same person is present during roentgen work corresponding to not more than five watt-hours per annum. No one shall be exposed to direct radiation in such a way that the energy through the roentgen tube (expressed in watt-hours) divided by the square of the focal distance (expressed in m^2) exceeds one during one year.

Finally a short account of the »Advice and Instructions» now being worked out is presented here. This »Advice and Instructions» will supplement the radiation protection regulations and contain information enabling the doses occurring under different conditions with the various types of roentgen apparatus to be calculated with at least a good approximation. In addition it will contain comments on the regulations and is intended also to serve as a guide to the planning of radiation protection in new roentgen establishments, and in general to be of help in questions connected with radiation protection.

Tables, diagrams etc. will give the necessary information on the radiation output from roentgen tubes in different circumstances and the scattered radiation that may be expected with different primary radiation qualities and scattering objects. Information is also given regarding the protective properties of lead and other common protective and building materials. The radiation protective properties are given for large radiation fields as this was considered most suitable from the point of view of practical radiation protection technique.

In one section the demand for radiation-proof joints between two different shields or protective materials is given in detail, and drawings etc. exemplify methods of obtaining radiation-proof joints in various circumstances. The principle here is that joints etc. in radiation shields must not involve weakening of the protection.

Instructions aiming at reducing the radiation risks in diagnosis of patients are given in the form of diagrams and tables showing, for example, the dependence of the incident dose on the voltage, radiation filter, the ratio between the focus-skin distance and the focus-film distance, intensifying screens, film sensitivity, sensitivity of the fluoroscopy screen etc. Attention is drawn here to the importance of the eyes of the investigator being thoroughly adapted to the dark.

One paragraph gives instructions on detached radiation protectives such as protective aprons, gloves, mobile screens etc.

Special instructions are given for certain establishments, for instance those used for the investigation of infants and insane persons, where it has often proved difficult to attain satisfactory protection because the personnel are usually forced to hold the patients while the investigation is carried out.

Accounts of some cases of radiation injury and the circumstances connected with them draw attention to certain dangerous situations that occur relatively frequently.

In addition there is presented in the »Advice and Instructions» under discussion a clearly arranged summary of the laws and edicts which refer to roentgen establishments and roentgen work and also extracts from the circulars on roentgen work already sent out by the Institute of Radiophysics.

SUMMARY

In this paper, an account is given of proposals for the establishment of Swedish regulations on protection against roentgen rays. The proposals, drawn up on the basis of experience from more than 8,000 inspections of roentgen installations, are mainly founded on the principle that no person, except when undergoing roentgen treatment or examination should be exposed to irradiation above a certain limit. This limit has been put at 0.1 r per week. The dose mentioned applies to whole body irradiation as well as to irradiation of only parts of the body, with an exception for peripheral parts such as the hands and the forearms, for which 1 r per week is permitted. Regarding patients subject to roentgen treatment or examination, unnecessary irradiation should be avoided. Special caution should be observed when irradiating the sex glands, children and pregnant women.

A formal prohibition for persons in radiologic work to be exposed to doses above a certain stated limit would imply practical and legal consequences which might involve great inconveniences. Instead of stipulations on a maximum allowed dose, the proposals give some general rules which, although lacking the character of strict regulations should nevertheless be observed in the work.

The regulations mainly contain only the fundamental demands of radiation protection. Comments needed and advice and instructions have been separated from the regulations proper. Thus, future experience in the radiation protection field can more efficiently be put to use in this »advice and instructions» which can be amended and completed with less formalities than established regulations.

ZUSAMMENFASSUNG

In dem Artikel wird ein Vorschlag für schwedische Vorschriften zum Schutze gegen Röntgenstrahlen beschrieben. Der Vorschlag, der an Hand der bei mehr als 8,000 Besichtigungen von Röntgenanlagen gesammelten Erfahrungen ausgearbeitet wurde, gründet sich im Grossen und Ganzen darauf dass Personen, die nicht Röntgenuntersuchung oder Röntgenbehandlung unterworfen sind, eine gewisse Grenze übersteigenden Bestrahlungen nicht ausgesetzt werden sollen. Diese Grenze ist zu 0.1 r pro Woche gesetzt

worden. Diese Dosis gilt sowohl für den ganzen Körper, als auch für Teile desselben, ausgenommen perifere Körperteile, wie Hände und Unterarme, für welche 1 r pro Woche gestattet ist.

Für Patienten, die sich einer Röntgenuntersuchung oder Röntgenbehandlung unterziehen, sagen die Vorschriften, dass unnötige Bestrahlung vermieden werden soll. Besondere Vorsicht soll bei Bestrahlung der Geschlechtsdrüsen, sowie bei Kindern und graviden Frauen beachtet werden.

Da ein in den Vorschriften direkt angegebenes Verbot dagegen, dass in radiologischer Arbeit beschäftigte Personen Strahlendosen über einer bestimmten Grenze ausgesetzt werden, durch seine praktischen und juristischen Konsequenzen grosse Ungelegenheiten mit sich führen würde, hat man an Stelle von Bestimmungen über maximal zugelassene Strahlendosen für radiologisches Personal einige allgemeine Richtlinien gegeben, welche, ohne strengen Vorschriftscharakter zu haben, doch beachtet werden sollen.

In den Vorschriften werden hauptsächlich nur die grundlegenden Strahlenschutzforderungen angegeben. Notwendige Kommentare und Anweisungen sind von den Vorschriften getrennt worden, wodurch ermöglicht wird, dass in den »Ratschlägen und Anweisungen», die leichter als festgestellte Vorschriften geändert und ergänzt werden können, in der Zukunft gewonnene Erfahrungen auf dem Strahlenschutzgebiete besser verwertet werden können.

RÉSUMÉ

Dans cet article on trouve le compte-rendu d'une proposition au sujet des prescriptions suédoises concernant la protection contre les Rayons Rœntgen. Cette proposition, qui a été élaborée en se guidant sur les expériences faites au cours de plus de 8,000 inspections d'installations radiologiques, part, en substance, du principe que, sauf les patients soumis à un examen ou à un traitement par les Rayons Roentgen, personne ne doit être exposé à une irradiation dépassant une certaine limite qui a été fixée à 0.1 r. par semaine. Ces doses concernent aussi bien le corps tout entier que certaines de ses parties, exception faite pour les organes périphériques comme les mains et les avantbras, pour lesquels on tolère 1 r par semaine. Quant aux malades examinés ou traités par les Rayons, les prescriptions veulent qu'on évite toute irradiation superflue. Il faut user de prudence particulière au niveau des organes génitaux, ainsi que lorsqu'il s'agit d'enfants ou de femmes enceintes.

Vu que, si les prescriptions avaient comporté l'interdiction directe d'exposer le personnel radiologique à des doses de Rayons dépassant une limite determinée cela aurait pu auvoir des conséquences d'ordre pratique et juridique non dépourvues de gros inconvénients, on a préféré donner quelques directives générales en lieu et place d'ordonnances touchant la dose maximale; sans revêtir le caractère d'interdictions sévères ces directives doivent cependant être observées au cours du travail.

Dans les prescriptions ne figurent, en première ligne, que les exigences fondamentales concernant la protection contre les Rayons. Les commentaires requis ainsi que les conseils et suggestions, ont été séparés des prescriptions, ce qui permettra, à ces »conseils et suggestions» — plus faciles à modifier ou à compléter que des prescriptions bien établies — de profiter par la suite des expériences à faire encore dans le domaine de la protection contre les Rayons.

FROM THE INSTITUTE OF RADIOPHYSICS OF THE KING GUSTAF V'S JUBILEE CLINIC, STOCKHOLM, SWEDEN (CHIEF: PROF. ROLF M. SIEVERT)

SOME CASES OF RADIATION INJURY IN RADIOLOGIC WORK[1]

by

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The supervision, carried out by the Institute of Radiophysics under the direction of the Royal Medical Board, over establishments in Sweden where radiologic work is carried on or where radioactive substances are stored has as its object »to gain the greatest possible security against causing injury, through the effects of roentgen rays or radiation from radioactive substance, to anyone who is engaged in the work, or any person or animal that is the subject of radiologic examination or treatment, or anyone who is casually present where such work is being c rried out» (extracted from 3 § of the Swedish Act concerning supervision of Radiologic Work etc.). In the same Act paragraph 9 states that any person »who conducts radiologic work or possesses radioactive substance, immediately after cognizance of occurrence of injury which may be assumed to have connection with the work or the possession of such substance and to be of the nature that is described in 3 §, shall report the same to the Institute of Radiophysics».

The reason for the introduction of paragraph 9 was to give the Institute of Radiophysics the opportunity to take the necessary precautions required through the injury which has occurred, at an early stage. It is obviously of importance that an investigation into the causes of an injury shall take place as quickly as possible so that it can be confirmed, whether it really has been caused by the radiologic work or not, and so carry out such completion of the radiation protection or alteration in working-methods that may be deemed necessary. For this reason it is necessary to confirm the radiation dose that gave rise to the injury, which may be done by direct dose-measurements or through estimates based on earlier ex-

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perience. Knowledge about radiation injuries, their cause and the radiation dose that caused them is clearly of great importance in radiation protection work. In too many cases the possessor of an apparatus has not observed his responsibility to report injury that has taken place or has delayed reporting it for so long that it has no longer been possible to reconstruct the detailed circumstances accompanying the origin of the injury.

The definite radiation injuries that have come to the notice of the Institute of Radiophysics have been of two kinds: local injuries (chiefly skin injuries) and blood damage. The causes of the local radiation injuries, which almost without exception are brought about by faulty working-methods, are usually easier to confirm than the causes of blood damage. First of all the type and site of the injury give a good lead to the determination of what gave rise to it, to which is added that it has been found in the cases investigated by the Institute that they have been caused solely by primary radiation, which facilitates the determination of the radiation dose and the technical facts. Secondly, injuries of a local nature are often of an accidental character or are caused by fortuitous circumstances which are known either by the injured person or somebody else.

Against this, radiation injury, which shows as blood-damage, is usually the result of smaller, hardly noticed carelessness in the radiologic work over a long period of time, or of insufficient radiation protection. Blood-damage differs from local injury in that at the commencement the injured person is not subject to discomfort and so also runs the risk that he may unknowingly continue to subject himself to injurious radiation.

With repeated inspections of premises where radiologic work is carried on or where radioactive substance is stored the supervisory staff of the Institute of Radiophysics, using radiation protection measurements as a basis, try to reduce risks by improving protection or by recommending alterations in technique. In a case where a radiation injury is suspected by the supervisor it is prescribed further that the person concerned shall undergo blood examinations.

Knowledge of the cases showing signs of incipient pathological blood-changes is also obtained from the reports of the medical examination that persons engaged in radiologic work are required to undergo every year. Such reports are sent regularly to the Institute of Radiophysics thus enabling any necessary precautions to be carried out quickly.

As already pointed out, the legal obligation to report suspected radiation injuries is not always observed. For this reason it is unfortunately impossible to obtain statistics which include all cases of radiation injuries since the passing of the Act in 1941. The National Insurance Board which deals with cases of compensation for loss of income caused through industrial disease or accidents which occur at work has during the period

1941—1949 only had some twenty cases of presumed radiological injury reported to it. Decisions on five of these cases have not yet been reached. Where decisions have been reached three quarters of the cases were of such a kind that compensation was authorised, and in the others it was considered that the injury could not be regarded as having been caused by radiation.

Investigations carried out at those private insurance organisations with analogous types of insurance have revealed no reports of radiation injury.

There is every reason to believe that the actual number of radiation injuries is considerably greater than the number reported to the National Insurance Board. This is particularly regrettable as by omission to report a radiation injury that does not appear at the moment to be of a serious nature, the injured person may lose the right to future compensation.

Below is given an account of some radiation injuries which have occurred in Sweden during recent years. The information has been obtained with the help of hospital records, reports to the National Insurance Board and the Institute of Radiophysics supervision reports and administrative records.

Case 1. This case concerns a nurse who was born in 1911 and who has been working as a roentgen nurse in a roentgen diagnostics department since 1938. She was daily holding patients for the photographing of extremities and skulls and has presumably often had her fingers exposed to primary radiations. Between 1944—1945 her fingers began to show signs of atrophy, this being accompanied by slight desquamation of the skin. She then became more careful and only continued to hold patients for a few times each month, when the desquamation ceased. In spite of her increased care the radiation injury reappeared in a more aggravated form during the summer of 1947, skin began to peel off and ulcers appeared on most fingers. She was then completely removed from radiologic work and by the end of September in the same year the sores were healed; even the desquamation had ceased although the atrophy still remained. Under the strict condition that she did not submit her fingers to radiation she was allowed to return to roentgen work in January 1948.

Case 2. A female clerk, born 1920, and since 1942 employed in a miniature mass radiography omnibus. The work consisted of stamping the patients' roentgen record sheets and assisting the patients in the bus.

The Institute of Radiophysics examined the establishment for the first time on 17th May 1943 and found that, if the existing radiation protection devices were effectively used, the personnel were not subject to a total radiation dose of more than 0.4 r per week. This dose was appre-

ciably below the dose that was at that time considered permissible for persons engaged in radiologic work. Nevertheless, instructions were given that the greatest possible care was to be taken as the dose registered was strongly dependent on the working-methods of the personnel.

The establishment was examined for the second time on the 9th April 1945, when it was found that there was a substantial increase in the risks to the personnel, who now appeared to be subject to a dose of about 3 r per week. The increased risk was caused by a substantial rise in the scope of the work. Because of this the Institute issued the following instructions.

»An inspection has been carried out and dose-measurements have been made. From these it appears that in view of the greater amount of work being carried out the radiation protection is unsatisfactory. Therefore, work may only proceed if the following precautions are at once taken:

A radiation protection screen will be erected with a protective power equivalent to not less than one millimeter of lead for protection of the clerk. The clerk will be instructed that whenever exposures are made she will be behind this screen. Also, technicians and nurses shall, during exposures, remain behind their respective radiation protection screens. In cases where it is absolutely necessary to hold the patient during exposure (especially during the examination of infants) and it is not possible for a relative to do this, temporary personnel shall be used who are not otherwise engaged in radiological work.

A monthly blood test will be made of all personnel employed on the roentgen bus, and reports of the haemoglobin content and red and white cell counts will be sent in to the Institute of Radiophysics together with two unstained blood smears for each person.

When experience has been gained from the instructions stated above the Institute of Radiophysics will re-examine the question of further precautions that may possibly be necessary.«

The increased risks in the work caused the Institute to inspect the establishment more frequently and four inspections were carried out in six months. Experiments were carried out with temporary shields erected during the inspections in order to find how the radiation protection arrangements could be best improved. During the summer of 1946 the completed, improved radiation protection devices were inspected, and it appeared that they fulfilled the great need for protection required with mass miniature radiography work.

On the 31st August 1946, in spite of the Institute's efforts, the clerk showed the following blood-count after a test: Hb 75 %, red cells 3.9 million, white cells 2,400. Differential count: leucocytes: rod forms 3 %, segmented cells (mostly hypersegmented) 56.5 %, eosinophils 1 %, basophils 0.5 %, lymphocytes 33 % (4 % pathological), monocytes 6 %.

A check count of the white cells on the 2nd September showed 3,200 and on the 3rd September 3,500, and the clerk was recommended by the doctor to rest at home. On the 17th September the white cell count was 4,300 and on the 1st October the following results were obtained: Hb 70 %, red cells 3.7 million, white cells 2,700. A differential count on the 1st October showed no hypersegmentation. The clerk was admitted to hospital on the 10th October 1946 with a diagnosis of leucopenia, anemia and medullary injury. The last was established by sternal puncture.

After three weeks she was discharged from hospital and went to stay in the country in order to rest.

On the 6th December 1946 the following blood-picture was shown: Hb 80 %, red cells 4.0 million, white cells 5,800. Differential count: leucocytes, rod forms 4 %, segmented forms 59 %, eosinophils 2 %, lymphocytes 22 %, lymphoblasts 2 %, monocytes 11 % (some hypersegmentation still remained). On the 6th January 1947 the patient was discharged as cured.

Case 3. During the Institute's inspection of the roentgen establishment of a private dentist it was discovered that a male dentist employed there (year of birth 1904) was himself holding the dental film during exposures: he used to hold the film between 5—10 times per day. The exposure-time was about 2—4 seconds, and radiation measurements showed that the hand which held the film could have received 3—4 r during one exposure only. He had been using this technique for about five years. At the time of the inspection his hands showed a deep redness and desquamation accompanied by blister formation with a watery secretion (see figs. 1 and 2). If one calculates the total dose which the hands had received during the five years (he changed the hand used from time to time) it is discovered that each hand can be presumed to have received a dose of about 15,000 r. The extent of the injury appeared to correspond to the calculated dose which had been, of course, split up. The dentist ceased to hold the film and after a few months the reaction had disappeared and there has since been no relapse.

During the inspection the dentist was very surprised when the supervisors connected the injuries to his hands with the fact that he held the films during exposure. He had thought himself that the injuries were caused by oversensitivity to some of the chemicals used in his work, in spite of the fact that the changes in the skin had not been reduced although he had taken great care in his work.

Case 4. An engineer, born in 1924, had worked with a roentgen diffraction apparatus and on one occasion in 1947 had been engaged on an adjustment of the roentgen tube as the anode was not well-centred.

He thought that during this he exposed his left hand to primary radiation. About three weeks later, on the three ulnar fingers of his left hand, an erythema appeared which later started to weep copiously.

After treatment from a doctor the injury was completely healed after a month. After this he carried on with roentgen work but thinks he did not expose his hands to primary radiation during this. In spite of this he noticed an increasing atrophy of the skin on the injured fingers. Towards the end of June 1949, probably after exposure to the sun, blisters appeared on the same fingers, accompanied by swelling and pain, which soon broke down into quite widespread sores. He was treated at a skin clinic for ten days and after three months the injury was again completely healed. In the middle of November 1949 the pain in the three fingers, especially the ring-finger, again returned and he noticed reddish areas on these fingers where the skin was strongly atrophied. In the atrophied area there was complete epilation.

He was admitted to hospital on the 14th December 1949 where signs of necrosis were seen on the ring-finger (see fig. 3). He was treated with penicillin and the fingers were bathed with camomile tea. By the 22nd December the condition was noticeably better and the pains had ceased.

Figure 4 shows the appearance of the left hand at 13th January 1950. The pain in the fingers had then returned and on the dorsal side of the ring-finger was an ulcer measuring about 6×17 mm. Induration was present over an area of about 20×30 mm. The patient was quite convinced that it would be necessary to amputate the ring-finger, which had caused the greatest trouble all the time. Because of ulceration he had lost five working-months during 1949 and, on the 20th January 1950 the finger was amputated. During careful questioning of the patient in order to obtain a reconstruction of the circumstances giving rise to the injury he stated that during centering of the roentgen-tube he happened to subject his left hand to primary radiation for a period of about ten seconds at a distance from the anode which varied between 4—6 cms. The roentgen tube which was equipped with a copper anode and a Lindemann-window operated at 35 kV and 20 mA. With reservation for exposure time and distance, because of the fact that the information was obtained from the patient two years after exposure, it appears from radiation measurements carried out that he was subject to a single dose at one time of about 8,000 roentgen on his left hand.

The danger in work with roentgen diffraction apparatus is clear. Because of the very great dosage-rate at the window of the roentgen tube — in the above case about 1,000 r per second — an exposure of only a few seconds in unsatisfactory conditions can cause grave radiation injury.

Case 5. This radiation injury was obtained whilst working with radium. A nurse, born in 1907, was working in a roentgen therapy department since 1943 and in connection with this spent a certain amount of time on radium work, often using her hands to handle radium needles and plane preparations. The number of radium treatments in the department during 1946—1948 varied between 150—175 per annum. During the inspection of radium work carried out by the Institute of Radiophysics in 1945 the touching of radium needles and preparations with the fingers was forbidden and instructions were issued that especially dangerous work should be carried out by persons who were only engaged in radiologic work for a short time. These instructions do not appear to have been regarded with sufficient care, as reminders that these instructions should be observed were issued during inspections in 1947 and 1948.

In the summer of 1947 this nurse began to notice a certain dryness on the volar sides of the hands and, on the suggestion of the inspector, visited Radiumhemmet in Stockholm. There it was found that in addition to this dryness there was also atrophy of the fingertips present, especially in the first and second fingers of the right hand (see fig. 5), and the commencement of fissures in the right thumb could be noticed. It was considered that the injury would not give any future trouble and the patient was advised to take great care in roentgen and radium work and preferably completely to discontinue radium work.

Other cases of local injury following radium work have occurred since the supervision activity commenced but these are caused by many years of such work: none are of a serious nature and in many cases the injured person has ceased to work with radium.

HULTBERG (Acta Radiologica Vol. XXXII, p. 17, 1949) has earlier given accounts of three cases of radiation damage treated by him which have occurred in Sweden; two of these concern persons who were engaged in radiologic work. The third concerns a radiation injury caused by a roentgen technician using a diagnostic apparatus in an attempt to bring about an abortion in a young woman.

The radiation injuries reported here have been incurred by people engaged on radiologic work. Some examples of injuries contracted by patients during roentgen examination are now given.

Case 6. A female patient, born 1888, was admitted for a fracture of the supra-condylar region of the left humerus. Repositioning was carried out on the 11, 12 and 15 November 1946 using fluoroscopy. From information collected it appears that the total time for the three repositionings was about 100 seconds. Fluoroscopy was carried out using a Siemens »Heliosphere» apparatus and with the help of a cryptoscope. Through an oversight the fluoroscopy was carried out using a tube current

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

of 10 mA, that is, the current intended for use in photography; the voltage across the roentgen tube was about 55 kV. The distance between the focus of the roentgen tube and the patient's skin was not more than 6—8 cms. About three weeks after the repositioning the patient began to be troubled by pain in the elbow and, when the plaster-bandage which had been applied was removed on the 15th December 1946, a red shallow sore having the size of the palm of a hand was found on the surface of the dorsal side of the elbow-joint. The patient was in great pain. By the 15th January 1947 the sore was healed with the exception of an area measuring about 30×30 mms, and by 7th January 1947 the sore was completely healed. On readmission of the patient on the 22nd April 1948, an area of skin about 40×40 mms. on the dorsal side of the left elbow was found to be atrophic, thin and red; smaller surface ulcerations were also present. Skin grafting was carried out over this area on the 30th April which was successfully healed by the 28th July 1948, the skin being soft and not fixed to underlying tissues.

Using the above-mentioned information concerning the physical conditions during repositioning and with the help of radiation measurements on the apparatus used it was calculated that the patient was subject to a total radiation dose of up to about 1,700 roentgen during the three exposures in a period of five days.

Almost analogous with the above case is the following:

Case 7. This concerns a woman, born 1919, who underwent repositioning for a fracture of the left radius on two occasions with an interval of one month. The total time of exposure to radiation was about 60 seconds and the calculated dose 1,000 r. Radiation injury was observed when the plaster was removed ten days after the last operation. A part of the dorsal side of the patient's wrist was reddish and gradually watery blisters appeared. After about one month the changes were healed and since then the patient has shown no further skin-changes.

Case 8. A woman, date of birth 1887, was admitted to hospital with a fracture of the left hip. The nailing of the fracture was carried out with roentgen control and during the operation three frontal and three lateral pictures were taken. During a check at the policlinic a good six months later a sore with an area of about 10 × 10 mm. was noticed on the inside of the left thigh high up in the groin; the skin surrounding the sore was red. This healed after a few months and now all that can be seen is an unpigmented skin surface.

The conditions when the three lateral exposures were made were as follows: a Siemens »Heliosphere» apparatus was used with a voltage of 55 kV, current 10 mA, and a focus-skin distance of 7 cms: exposure time was about 10 seconds. This means that during the exposures for the three lateral pictures the patient received a total skin-dose of about 500 r on the inside of the thigh. As is known, the skin here is more sensitive to radiation than that on many other parts of the body.

In this case the radiation injury is believed to have been caused by the exceptionally short focus—skin distance that was used.

As was stated earlier, during their inspections supervisors often come across examples of unsuitable working technique which, if used, will in all probability lead to radiation injury either locally or to the blood. Unfortunately the supervisors' instructions for the effecting of a risk-free radiologic work are often met with a misunderstanding of the fact that the necessary interference is there in order to benefit the health of both patients and personnel. The arguments against the supervisor's prohibition and instructions that are often met is that the faulty working-technique occurs so seldom compared to the other work and that there has been no apparent decrease in health in spite of the fact that the work has been carried out in the same way for such and such a time.

That a faulty technique seldom occurs is no reason for its continuance. On such rare occasions it is possible for those engaged on the work to receive a radiation dose which may be many times greater than the total received in the whole of the other work, or the patient may be submitted to a dose which is considerably greater than is necessary for the carrying

out of the work. All precautions which may be taken to prevent people from suffering injury should obviously be taken before the injury has occurred.

Because of the cumulative effects of roentgen radiation it is impossible to know, before a perceptible impairment of health has occurred, how many roentgen a person can still absorb without transcending the threshold over which injury is imminent.

SUMMARY

A brief discussion is given on the occurrence of radiation injuries in general and the importance of the cases being adequately and rapidly investigated in order to secure prompt execution of the protective and other measures needed. Reports on five radiation injuries among radiologic workers and three among patients undergoing roentgen examination follow.

ZUSAMMENFASSUNG

Diskussion über das Vorkommen von Strahlenschäden im allgemeinen und über die Notwendigkeit einer frühzeitigen und genauen Untersuchung der Fälle, um schnelle Durchführung der notwendigen Strahlenschutzvorrichtungen und anderer Massnahmen zu sichern. Ferner wird über fünf Fälle von Strahlenschäden unter radiologisch Beschäftigten und drei unter Patienten, die Röntgenuntersuchung unterzogen wurden, berichtet.

RÉSUMÉ

Le travail apporte une courte discussion sur la fréquence des dommages par irradiation en général et l'importance de reconnaître vite et exactement ces cas, pour que les dispositions nécessaires de protection contre les Rayons, et d'autres mesures, soient prises sans aucun retard. Suit la relation de cinq cas de lésions par irradiation chez des personnes occupées à des travaux radiologiques, et de trois autres parmi des malades qui furent examinés aux Rayons Roentgen.

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